Commentary
URBAN ORGANIZATION

LIVING seems to be getting more difficult. There has been some outcry recently at the rapidly rising cost of building land around London; tart, and meaningless, comparisons have been made of the cost per square foot of land to build houses on as compared with the cost per square foot of tiles or carpets or hardwood. The grotesque and growing traffic congestion still seeks a social aperient if the present progress of procession towards a halt is not to be arrested. The log-jam of traffic frustration in our large cities is one of the wonders of the modern world. Yet it emerges that recent attempts to stagger holidays have encountered difficulties and adjustment of working hours is unpopular.

Living indeed seems to be getting more difficult and more expensive. At least the difficulties of urban living seem to become, daily, more baffling and the more industrialized a society the higher the proportion who live in cities. Man is a gregarious animal and the size of the herd is limited by the water and the grazing. For elephants this always has been, and still is, a problem though man has long ago contrived to pipe his water and transport his crops. The economic and social pressures, hallowed by David Ricardo as 'division of labour' provide the elementary social surface tensions which increase the urban concentrations. Indeed the largest markets both of goods and of services are of course to be found in the largest concentrations. The city is simply the *supermarket* of society. In spite of our improved transport and communications, in spite of conscious, planned attempts to prevent it, it is remarkable how large cities have grown larger since the war. If Helen's face did 'launch a thousand ships' what can be done to launch a thousand towns?

Some of our recent follies are obvious. The more paralysed the traffic the shorter the individual mean free path so that land values for housing are bound to rise. Old city-centres were not laid out for modern traffic, and hence it is said that concentric expansion should be replaced by a linear development, like beads rather than bubbles. This may be so, though surely when the mean, individual velocity falls below a walking pace, the logical conclusion is to bale out and walk. There are the other, less publicized, services which require a thought also, services like water and lighting. Even if we examine the needs not of a mega-metropolis like London but of an industrial city like Sheffield we find in the last annual report of the Water Committee to the City Council: that the income was over £1m; that there are over 1000 miles of water mains; that the average daily supply was 35,522,348 gallons. Of course it is sensible and efficient to concentrate such a service for so many people. But finding water for urban authorities even in a notoriously wet island has become a serious occupation.

Perhaps we should become troglodytes; some say we are. Certainly the improvements in industrial lighting have been such that, for instance, the life-time of cold-cathode fluorescent lamps is now much greater than that of the decorations. Lights and lighting can now be arranged as permanent fittings. The cost of lighting is such that it is cheaper, regarded solely as a lighting problem, to illuminate by artificial means alone and dispense with natural lighting. Factories and office blocks can be and are being designed with this in mind. It is no longer necessary to pay attention to daylight.

This is our 'civic problem'. The technical solutions to the various component problems, how to house, to comfort, to transport, to employ, to entertain, have each far-reaching and important independent solutions. Nothing could be more effective regarded as a problem of individual transport than that each individual should have his own individual chariot. The practical social consequence is acute traffic arthritis. It is probable that the resistance to attempts to stagger hours and holidays arises from 'leisure interests'. If this is so, it is in itself no bad thing. The outstanding fact, which stands out like the large inflamed thumb that it is, is that we simply do not know enough about the dynamics of living in cities. We know something, a little of comfort, entertainment, transport; we know little of the practical, actual, integration of these in urban living. There is an enormous amount of field work, of the social anthropology of living in cities to be done. And it is studies of the dynamics not of the statics that we need. It does not require an anthropological genius to tell us that better housing is better than poorer housing. But the interaction of housing, work, travel and entertainment—all that makes up urban living—that requires extensive field work, a lot of thought and experiment. Why do people live in cities? What do they do? How far will they travel? How do they balance leisure and travel?

We should all begin by reading Lewis Mumford. The longer we protract the horror, the worse it will be.

B

INSTRUMENTS FOR SPACE RESEARCH

R. L. F. BOYD

Department of Physics, University College, London

Much is written in these days about space research rockets and their scientific objectives. This paper is concerned instead with the instruments they carry, with the means by which the measurements are made. Detail cannot be given in so short a space but it is shown that generally the instruments differ in form rather than principle, their design having taken account of the stringencies of their environment, and of the need for reliability and low power consumption. This is the last article in the *Microinstruments* series.

The Scope of the Problem

HALF a century ago, those who thought about the exploration of space thought of it primarily as adventure. Man was central, and even if research was considered, the vehicle must carry the investigator and all that was necessary for his life in space and his safe return. As soon as the pursuit of space science becomes the objective the presence of man is seen to be a nuisance, at any rate for the sort of scientific projects currently planned. His five senses, rarely adequate for contemporary research, are even more limited in the vacuum of space. Their work must be done by instruments and the guiding role of man must be mediated by programming, automation and radio command control.

Broadly speaking the range of sensing devices required covers the detection and study of:

(*1*) *Neutral matter and its composition*—This includes both ambient gases and meteoric material. No doubt in the near future the material of other celestial orbs will be included.

(*2*) *Charged particles*—Here a wide range of phenomena are involved from the low energy particles of the ionosphere through the medium energy corpuscles of the solar streams and Van Allen belts to the high energy nuclei stripped of their electrons, which constitute the cosmic rays.

(*3*) *Electromagnetic radiation* — The whole spectrum is included from the audio frequency radio waves of *whistling atmospherics* through the infra-red, visible, ultra-violet and x-ray regions to the energetic γ-rays of the cosmic radiation.

(*4*) *Magnetic fields*—Not only are magnetic fields of importance in the neighbourhood of the earth but the fields due to the sun and other components of the solar system and due to the motion of ionized gases in space must also be measured.

(*5*) *Electric fields*—This is one of the most difficult quantities to measure in a space vehicle. Such fields may, however, be very important. It has recently been suggested, that certain temporal variations in the energy spectrum of cosmic rays should be attributed to a heliocentric field in which the earth has a potential of over 10^9 volts.

(*6*) *Gravitational fields*—To date these have been studied in connection with the distribution of matter in the earth. Their relevance in connection with the General Theory of Relativity, however, is not being overlooked.

Together with the many and varied sensing instruments much ancillary equipment is also required. Apart from the vehicle itself and the instruments to control and monitor its behaviour there is a need for power sources, data storage and recovery systems (telemetry), programming and time-keeping equipment and automation devices such as stable platforms, sunseekers and so on.

The Environment

The most serious of the special environmental conditions to which space research instruments are subjected is temperature variation. Once in orbit a satellite's temperature is determined by the condition that the radiation received from the sun and the earth and the heat generated from any internal sources, must be radiated away again. Only very small satellites suffer large alternations of temperature on passing into and out of the earth's shadow. Larger vehicles assume a temperature which only fluctuates slightly about a mean, determined chiefly by the nature of the vehicle's surface. This mean, however, will vary as the orbit position and shape changes in relation to the sun or as the nature of the surface changes.

Inadequate attention to these problems could readily result in an equilibrium temperature very far from that intended. Even when all possible care has been taken it is necessary to design equipment not only to withstand a temperature range that may exceed 0–50°C but also to retain its properties, such as frequency stability, amplification, minimum electrical noise level, within the limits prescribed by the experiment.

Figure 1. Miniature transistor amplifiers used in connection with optical and ionospheric experiments in Skylark rockets. Left: high gain pre-amplifier; right: amplifier with logarithmic response (University College London)
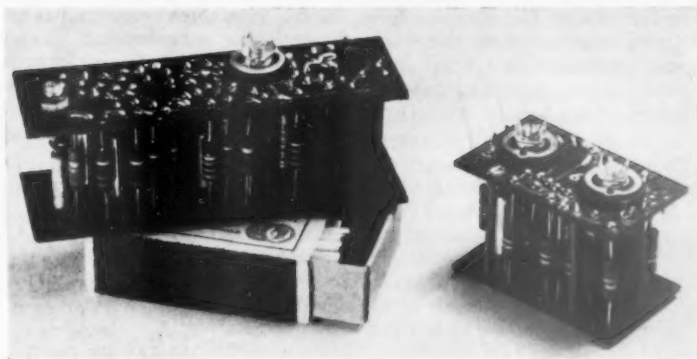
In a satellite the mean temperature reached will depend on the precision with which the desired trajectory is attained. For a deep space probe the problem is more severe as the vehicle encounters a wide range of thermal conditions as it moves from the neighbourhood of the earth out into space. The Russian approach to these problems has been quite sophisticated. *Sputnik III* had a system of thermostatically controlled radiation panels. *Lunik I* was separated from its final rocket stage and allowed to rotate so as to maintain the same average aspect relative to the sun. *Lunik III* was arranged to behave in a similar way, though its motion was arrested while the moon photographs were obtained and restarted immediately afterwards so as to rotate whilst the film was developed and telemetered. Several Russian vehicles have been filled with nitrogen circulated by a fan, to assist in maintaining the desired thermal conditions.

Acceleration fields, especially vibration, during launch constitute another important problem, though it is probably true to say that they are more important as regards mechanisms and structures than as regards electronic instrumentation. Miniaturization, undertaken for weight and power economy, makes possible a system in which adequate mechanical strength is not difficult to achieve. The accelerations and vibrations to which satellite vehicles are subjected do not usually exceed 15 g, but small research rockets may subject their instruments to as much as 100 g.

Mechanical strength for circuits is usually provided by casting them in an epoxy resin. Occasionally this is also done in order to prevent electrical breakdown in unpressurized systems employing high tension. For satellite (as distinct from vertical sounding rocket) applications foam resins are used to reduce the weight.

Weight and, even more important, power considerations make for the wide use of transistors and other semiconductor devices. Their robustness and low voltage operation are further advantages, though their sensitivity to temperature changes frequently makes the circuit design stringent and often necessitates the use of silicon rather than germanium devices. Semiconductors suffer radiation damage from fast particles which disrupt the crystal lattice. Laboratory experiments and experience with satellites, especially *Vanguard I* (the 'grape-fruit' satellite, still in orbit) tends to show that such damage from cosmic or other radiations is not likely to be a serious problem for vehicles with useful lives of about one year.

More serious is the effect of micrometeoritic dust. Impact with individual meteors capable of doing significant damage, is likely to be a rare event, but erosion of optical surfaces by interplanetary dust may be important in some cases.

General Instrumentation

The power source and data recovery systems are, of course, a vital part in any celestial laboratory. In vertical sounding rockets batteries, commonly of the silver–zinc or mercury–alkaline type, supply the power, high tension being obtained by transistor multivibrator invertors. Semiconductor devices, such as Zenner diodes are also used to provide voltage stabilization where necessary. In satellites and deep space probes solar batteries are now almost invariably used if the life is to be more than a few weeks.

The weight of a solar battery system with accumulators to provide power during the dark part of an orbit, is about 2 lb/W. The limitation on power available is thus not weight but surface; about 500 cm^2 is required to provide a randomly oriented

satellite with 1 W. Atomic power sources show promise, and it may be that in the future higher power demands will be met in this way.

Telemetry systems employ a wide variety of methods for encoding the data. Generally the information is contained as frequency modulation of a subcarrier which may be amplitude or frequency modulated on the main carrier. Both the U.S.A. and U.S.S.R. have made some use of pulse modulation, in which the data is contained in the length of a pulse (or interval between pulses). More and more data are being transmitted in digital instead of analogue form; this often improves the information carrying capacity of the system and assists in data handling.

In order to transmit data for several different quantities *time-multiplexing* is most usually employed. This involves an electronic switch which connects the transmitter in sequence to the signal sources supplying the various data. In this way fifty (or more) different information channels may be sampled, each of them fifty times a second.

It is not unusual to have more than one telemetry transmitter. Generally one is kept operating continuously while another may be switched on by radio-command, though in deep space probes power

requirements may necessitate the switching off of all transmission for long periods. A continuously operating telemetry transmitter or, in vertical rockets, often another transmitter specially intended for the job, provides a radio beacon to enable the vehicle to be tracked and its position plotted.

Frequently storage of data in a vehicle is required. For vertical sounding rockets, this may dispense with telemetry and the data may be recovered on return of the vehicle. For satellites data storage is at present necessary if world wide coverage is required, because of the limited number of telemetry receiving stations. For deep space probes, data storage is useful in order to enable adequate data to be transmitted over the limited capacity of the telemetry link. Data obtained in a short space of time may be telemetered at leisure when the vehicle's position is more satisfactory. *Lunik III* provided a classic example of this. The data on the far side of the moon was obtained rapidly as photographs. It was then scanned off slowly after the vehicle had returned to the neighbourhood of the earth.

Accurate time keeping in space vehicles is done by crystal clocks, though the requirements of relativity experiments have led to work being started on satellite borne atomic frequency standards. Tuning
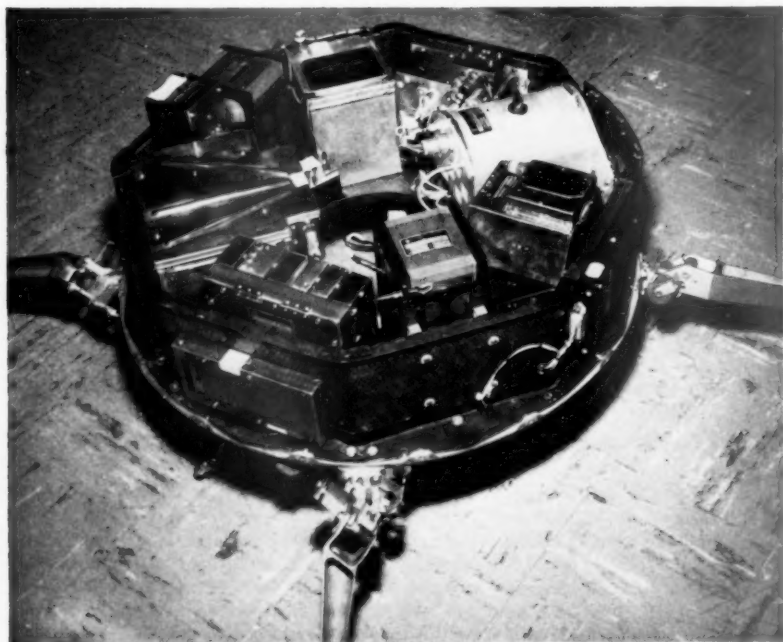

Figure 2. Instrumentation deck of Pioneer V showing equipment for monitoring cosmic rays and ionizing radiation (By courtesy of Space Technology Laboratories, U.S.A.)

forks have also been used, as have electric motors fed from a voltage stabilized source when the flight is short and precision is not required.

Experiments in Space

Neutral Matter

The gases of interplanetary space are largely ionized, but the envelope of air around the earth only merges slowly into it and there is a broad region beyond the reach of balloons in which its temperature, composition and motion are studied by rocket techniques.

Composition of the atmosphere is investigated in several different ways. Below 90 km evacuated bottles have been used to recover samples of ambient gas and to return them for micro-analysis. The very small mass of the sample presents severe problems. At greater heights rocket borne mass spectrometers have been used. These are of the time-of-flight type in which ions produced by an electron stream are accelerated to a known potential, and their velocity (and hence mass) is measured by their passage through a system of r.f. fields. Rare constituents of the atmosphere and at great heights the main constituents have been examined by their absorption of solar energy.

Temperature and motion up to 90 km are best studied by measurements on the velocity of sound propagation from grenades carried in the rocket to microphones on the ground. Above this height winds are measured by observing the motion of glowing gas, produced either by ejecting a catalyst such as nitric oxide capable of photochemically recombining the ambient atomic oxygen or by ejecting sodium vapour which glows in the twilight rays of the sun. Temperature may also be obtained from ground observations of the Doppler broadening of the sodium resonance radiation, though more generally it is inferred from density by way of the hydrostatic equation. Some density measurements are made by pressure gauges of the ionization or thermal conduction type but generally greater precision is attainable by observing the motion of a body which is falling or in orbit, and inferring the density from the drag. Below satellite altitudes (about 200 km) spheres, either rigid or inflated, are ejected from a vertically flying rocket. Their motion is observed optically, or by Doppler tracking of a radio beacon in the sphere or by an internal integrating accelerometer which continually telemeters to ground the time interval required for a small weight in the centre to overtake the sphere by a few millimetres. At greater heights density is obtained from the rate of decrease of period for a satellite orbit.

Efforts to collect micrometeoritic material for analysis have not so far given sure results. Methods of collecting or detecting interplanetary dust have included grease cups, pitting of surfaces and penetration of foils, but by far the most common method has been the use of crystal microphones to respond to the micro-impulse. Anticoincidence circuits connected to two microphones are used to discriminate against creaking noises of internal origin.

Charged Particles

The concentration of electrons in the ionosphere is often measured by observing their effect upon the refractive index of the medium at radio frequencies. There are four main systems involving (1) measurement of phase velocity (by continuous wave propagation) over a path from rocket to ground and/or vice versa; (2) measurement of group velocity (for a pulse) over such a path; (3) measurement of magneto-optic splitting (Faraday effect) resulting in rotation of a plane of polarization as a result of the presence of the earth's magnetic field; (4) measurement of the local refractive index in an r.f. condenser consisting of, for example, the region between an insulated electrode and the body of the rocket. In all these cases the instrumentation follows standard miniature or sub-miniature radio practice.

The concentration of electrons and ions is also measured by collecting them on electrode systems of varying degrees of complexity (Langmuir probes). Here the main problems of instrumentation are electronic and may involve the measurement of small direct currents of order 10^{-10} amps. Even smaller alternating currents must sometimes be measured. Transistor amplifiers or hybrid amplifiers using thermionic electrometers together with transistors are employed.

Ion mass spectrometry is carried out by r.f. or pulse methods analogous to those used for the analysis of neutral gas. More energetic ions are detected in counters of the normal terrestrial types—Geiger counters, proportional counters, scintillation and Cerenkov counters. Use has also been made of counter telescope arrays, of magnetic fields for energy analysis and of photographic emulsions. All these techniques follow normal laboratory practice though often special emphasis on low power consumption must be given to the amplifier and scaling circuits.

Electromagnetic Radiation

Radiation in the radio-frequency range such as cosmic radio noise, normally prevented by the ionosphere from penetrating to the ground, is measured by miniature radio receivers. The important technical problems are the design of low

noise circuits and the provision of suitable aerials, with polar diagram not too dependent on vehicular aspect.

Not much work has been done in the infra-red part of the spectrum though some work on atmospheric water vapour has been carried out in a small solid-propellant rocket fitted with a sunseeking device. Work on visible radiation due to air fluorescence (airglow) is carried out by means of standard ' Venetian blind ' photomultipliers fitted with suitable filters. In the ultra-violet range a very great deal of work has been done using many different types of instrument, from simple photo cells or ionization chambers with filters to complete grating or prism spectrographs mounted in sunseeking systems. In the spectrographs photographic film is recovered in strengthened cassettes, but use has also been made of scanning spectrometers with photomultipliers as the sensitive element feeding the telemetry system. Some pioneer ultra-violet work was done with thermoluminescent phosphors which were excited by the solar ultra-violet and after recovery released a definite fraction of this energy in the visible spectrum on heating. X-Rays are measured both by photographic emulsions covered with suitable filters and by counters of the Geiger or proportional type.

Pictures in ultra-violet light have been obtained both of the sun and of the heavens. In the former case a double grating spectrograph was used to obtain an image of the sun in Lyman-alpha radiation. This strong hydrogen line is sufficiently isolated from other strong lines to make it possible to select it by a suitable slit before forming the final image. Raster type pictures of the sky are obtained by using the rotation and precession of the rocket to scan the heavens with photon counters or photo-multipliers whose field of view has been suitably restricted.

With improved vehicle stabilization and with close approach to other celestial bodies it will become possible to obtain pictures in visible light better than those obtainable from the ground. Indeed a notable start has already been made in this kind of work by the photographing of the far side of the moon by *Lunik III.* Unfortunately few technical details of the equipment are available.

Magnetic Fields

Magnetic fields are measured by three methods common in the laboratory: rotating coils, flux gates and proton precession. One of the main problems in these measurements involves the *degaussing* of the vehicle. This may be bypassed by measuring the e.m.f. induced in a coil rotating with the vehicle since under these circumstances the vehicular field is fixed relative to the coil, and rotates with it.

Flux gate magnetometers employ the effect of the ambient field on the saturation properties of the magnetic core of an inductance. To some extent the presence of the vehicle's field may be allowed for by the electrical adjustments of the instrument. Proton precession magnetometers use a coil to detect the magnetic field due to the precession of the magnetic moment of protons in a hydrogenous liquid. This precession results from the torque on the protons due to the ambient field after the protons have been aligned by a polarizing field and suddenly released. In *Vanguard III* an instrument of this kind was mounted on a long fibre glass protrusion from the satellite. On other occasions the complete sensor has been ejected from the rocket.

Recently work has been in progress on a *MASER* type of magnetometer using rubidium vapour. This instrument employs the Zeeman splitting of energy levels to give an a.c. field whose frequency is a measure of the magnetic field.

Electric Fields

Langmuir probes and shutter type field meters have been used in experiments on electric fields but it is difficult to obtain significant results because of the space charge sheath which envelopes an isolated body in space.

Gravitational Fields

To date no special instruments have been used to study gravitational fields but the study of the motion of satellites themselves has given much information on the field of the earth, its assymetry and the size of the equatorial bulge.

General Conclusions

While careful design and stringent testing are, of course, essential to successful space research, highly specialized techniques are relatively rarely required. Printed circuit construction and packaging densities of the kind employed in most hearing aids or other terrestrial transistorized equipment is adequate and generally gives sufficient strength. Mechanical systems are the most liable to failure.

In much work available space is a more serious limitation than pay-load capacity, and in satellites and deep space probes available power is more serious than either. Three main instrumentation problems are being faced for the immediate future: the provision of the precise and tele-controllable orientating systems required for astronomical (and other) work; the provision of radiocommunication links of adequate capacity and range and the recovery of systems from orbit. Equal in importance to these is the provision of adequate tracking, data handling and analysis equipment on the ground.

ISOLATION AND IDENTIFICATION OF VOLATILE FRUIT-FLAVOURS

D. S. BIDMEAD and D. WELTI

Unilever Ltd, Food Research Department, Sharnbrook, Bedford

The technique of concentrating and extracting volatile flavour components from aqueous juices is a major factor in the examination of fruit and vegetable flavours. A method is described for preparing a water-free concentrate of the flavour and separating its components by gas chromatography. Infra-red and mass spectroscopy, together with column and paper chromatography help to identify the isolated compounds.

SYNTHETIC flavour mixtures, particularly those which imitate the natural aromas of fresh fruits, have been used by the food-manufacturing industry for many years. Such mixtures are usually blended in an arbitrary way by a flavour chemist who, like a perfumer, uses his skill, judgment and experience to produce what is often a good imitation of the natural flavour. These synthetic products do not necessarily bear any resemblance in composition to the natural product, though in recent years the tendency has been to take advantage of new knowledge about the composition of the natural flavour in order to improve the synthetic flavour.

Apart from the application to the manufacture of food flavours, the identification of fruit-flavour components is important in the study of the metabolic processes occurring in the fruit during ripening, and in planning fruit-breeding programmes. It also provides an objective method of assaying flavours and a means of assessing the chemical changes which occur in the flavour during processing and storing fruit.

Early workers were faced with the difficulty of extracting very low concentrations of flavour components from a large bulk of aqueous material, followed by qualitative tests and the preparation of derivatives. They were, however, able to identify some of the more abundant and stable components, and the work of COPPENS and HOEJENBOS[1] on strawberry flavour is a classic example. These workers extracted 445 kg of strawberry juice with ether, distilled off most of the ether, neutralized the acids with sodium carbonate and dried the remaining ether solution. Removal of the residual ether left 86 g of neutral oil, containing a high proportion of the non-volatile and waxy material. The volatile material was distilled off under vacuum and then fractionally distilled. By repeated distillations and the preparation of derivatives, they were able to

identify a number of components, mainly alcohols, esters and free acids (*Table 1*). A mixture of these components however, did not reproduce the fresh aroma of strawberries[2].

Table 1. Volatile flavour components of strawberry (COPPENS *and* HOEJENBOS[1]; *courtesy Rec. Trav. chim. Pays-Bas*)

Ethanol	Ester of butyric	Cinnamic acid
Ethyl acetate	acid	DL-α-Terpineol
iso-Amyl alcohol	*n*-Hexanol	1-Borneol
Ethyl or methyl	Acetic acid	Terpin
caproate	*n*-Caproic acid	

During the past ten years, research into flavour problems has been helped considerably by the development of new techniques and instrumental aids to the analysis of complex mixtures. Gas chromatography in particular, is an invaluable tool for the separation of the components of an essential oil, and with infra-red and mass spectroscopy, gives every chance of solving what was formerly regarded as an almost insoluble problem.

Concentration of the Flavour

The success of any investigation into the components of a volatile flavour depends very largely upon the methods used to concentrate and extract the flavour from the fruit. Direct extraction of the juice or pulp with solvents is not acceptable, because many non-volatile compounds are extracted at the same time, and these may be very difficult to remove during the concentration at a later stage. Much of the pioneering work was done in the U.S.A., where the production of concentrated fruit juices without loss of aroma has been studied extensively[3]. The first requirement of any extraction technique is to give the maximum yield of flavour from a given quantity of fruit, and secondly, the concentrate must be truly representative of the natural flavour, and in a suitable form for direct analysis, for example by gas chromatography.
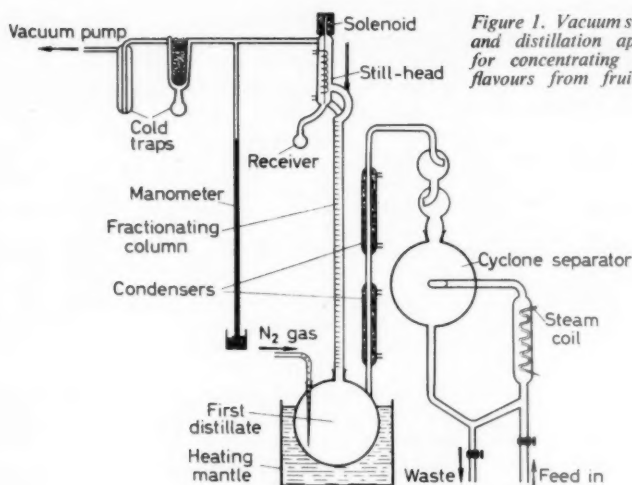
Figure 1. Vacuum stripping and distillation apparatus for concentrating volatile flavours from fruit juices

In this laboratory, a technique has been evolved which is applicable to any volatile or steam-volatile flavour from an aqueous juice or extract. The flavour is stripped from the juice under reduced pressure and concentrated by fractional distillation[7]. The final distillate is then solvent-extracted to yield a water-free liquid mixture of the flavour components.

The juice is extracted from the fruit by pressing in a hand operated hydraulic press exerting a pressure of 300–500 kg/cm². This gives a clear juice free from pulp, an important factor in the next stripping stage, and does not produce excessive aeration of the juice. Seasonal fruits such as strawberries, raspberries and other soft fruits are usually stored in the frozen state and can be pressed whilst still frozen, so that any deleterious enzyme action on the juice which might alter the flavour, can be kept to a minimum. Large fruits, *e.g.* tomatoes and apples, are minced or finely chopped before being pressed.

As soon as possible after pressing, the juice is fed batch-wise into a circulating evaporator, which consists of a short, steam-heated flash heater connected to a cyclone separator (*Figure 1*). The whole apparatus is operated under reduced pressure (30 mm Hg) so that the juice boils and de-aerates simultaneously during its short passage through the flash heater. The juice and vapour pass into the cyclone, where the vapour is led into the first set of condensers and the juice is returned through the flash heater. Juice is fed into the apparatus at a controlled rate to restrict foaming and to prevent any carry-over of coloured material or solid into the

distillate. When the level of the juice in the separator reaches the side entry from the flash heater, the juice feed is stopped, and the contents of the evaporator allowed to circulate until the required proportion of the original volume has been evaporated. A headspace above the level of the juice equal to at least half the volume of the cyclone separator is essential to allow for foaming which can be very troublesome with some fruit juices, *e.g.* tomato, if these conditions are not observed. Some juices contain a high proportion of pectins which tend to form gels readily, especially when being evaporated. These are treated before distillation with pectinase, an enzyme which prevents gel-formation by de-methylating the pectin. The proportion of water evaporated from the juice must be determined by trial, as it varies for different fruits, for example only 10 per cent by volume of apple juice need be evaporated in order to capture all the volatile flavours[3], whereas 50–75 per cent of the water in grape juice must be evaporated because some of the flavour components are tenaciously held in the water phase. When the volatiles have been stripped from the juice, the residue is discarded and a fresh batch of juice is introduced. The process is continued until all the juice has been stripped and the product is an aqueous distillate which has the characteristic aroma of the original fruit. The concentration of flavour achieved at this stage may be from two to ten-fold in volume, depending on the starting material.

The first distillate is still a very dilute solution of the flavour components in water, and in the next

stage of the process the flavour is removed from the bulk of the water by distillation through a high-efficiency fractionating column. The circulating-evaporator part of the system is shut off, and the pressure increased to 160 mm Hg and maintained constant by a manostat in the vacuum line. The aqueous solution is heated, and nitrogen gas is bled into it to promote steady boiling. The vapours pass through a lagged column 650 mm long and 20 mm in diameter packed with Fenske helices, and are condensed in a magnetically operated reflux-dividing still-head. The column is operated under total reflux for one hour to establish equilibrium, and then the distillate is taken off slowly at a rate of one thirtieth of the total reflux. The volatile and steam-volatile components collect in the still-head and are removed as the second distillate. The concentration achieved at this stage is about a hundred-fold and the residual water in the boiler is left with only a faint 'cooked' aroma.

Throughout the whole of the stripping and distillation procedure the vacuum line must be guarded by traps cooled in solid carbon dioxide and alcohol to prevent the loss of volatile material into the pump. At the end of the fractional distillation the contents of these traps are added back to the second distillate which is ready for solvent extraction.

Solvent Extraction of the Flavour

The solvent extraction is one of the most important parts of the whole procedure.

The aqueous distillate from the fractionating column is saturated with ammonium sulphate in order to decrease the solubility of the organic components in the aqueous phase, and make the extraction with solvent more efficient. The aqueous solution is extracted with ethyl chloride in a continuous liquid/liquid extractor fitted with a mechanical stirrer (*Figure 2*). The fine dispersion of the solvent throughout the aqueous phase produced by the stirrer gives optimum conditions for extraction. Ethyl chloride is an excellent solvent for flavour extraction, but a solid carbon dioxide condenser must be used in place of a water condenser, since it boils at 12°C. The extraction can be run continuously for several hours if required, without appreciable loss of solvent. At the end of the extraction process, the solvent layer is separated from the aqueous layer, and immersed in solid carbon dioxide for several hours, preferably overnight. The residual water freezes out, and being heavier than the solvent, sticks to the bottom of the containing flask. The dried cold solvent solution can then be easily decanted into a clean dry flask ready for removing the solvent.

The solvent must be removed with every possible precaution to prevent loss of the more volatile components of the flavour mixture with the evaporating solvent. The solvent solution is therefore slowly distilled through a reflux column filled with Fenske helices and chilled by an ice-water jacket. A still-head fitted with a solid carbon dioxide condenser returns most of the condensate to the column, and only a very slow take-off is admitted to the receiver. In this way, the solvent can be removed without losing any flavour components. The residue of concentrated flavour mixture is transferred to a small stoppered tube which is stored in crushed solid carbon dioxide until required.

The yields of flavour concentrate vary considerably, according to the particular fruit being processed; 20 kg of fresh tomatoes will give not more than 0·25 ml of concentrate whereas the same amount of strawberries will yield up to 1 ml. These large quantities of the raw material which must be processed to provide a working quantity of the concentrated flavour, emphasize one of the main difficulties associated with this kind of investigation.
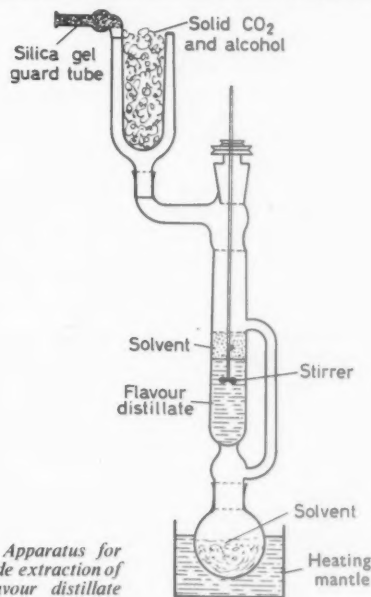

Figure 2. Apparatus for ethyl chloride extraction of aqueous flavour distillate

Separation by Gas Chromatography

The development of gas chromatography as an analytical tool by JAMES and MARTIN[4], greatly stimulated the study of complex food flavours. The technique is admirably suited to the separation of small amounts of volatile materials in a complex

flavour mixture. The most useful column packing for preliminary study of the composition of a flavour concentrate is *Celite 545* coated with 30 per cent by weight of *silicone oil 550*. This is packed into a column 4 ft. long and 0·25 in. in diameter, and can be operated at temperatures up to 250°C. About

column. Peaks collected at 75°C on the silicone chromatogram, are re-chromatographed on a column packed with a stationary phase of *polyethylene glycol 200* at a steady temperature of 75°C (*Figure 4*). If the components are to be examined by infra-red spectroscopy, *polyethylene glycol 200* cannot be used
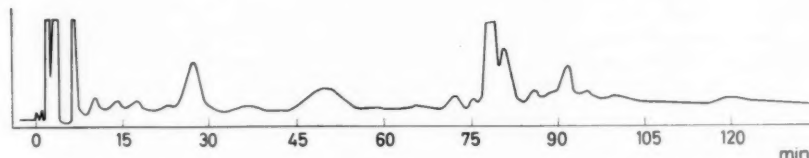

Figure 3. Gas chromatogram of strawberry flavour concentrate using silicone oil 550 as stationary phase. Column temperature range 75°–200°C
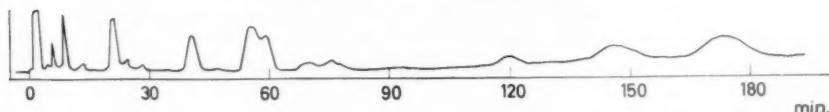

Figure 4. Gas chromatography of tomato flavour concentrate using polyethylene glycol 200 as stationary phase. Column temperature 75°C

40 μl of flavour liquid are applied to the top of the column, and the flavour components are eluted with dry nitrogen gas. The eluted components are detected by a gas density balance of similar pattern to that described by MARTIN and JAMES[5]. A thermal conductivity detector is not used because the components would come into contact with hot filaments and might be decomposed. At the beginning of an analysis, the column temperature is held at 75°C. After 55 minutes at 75°C the column-heater current is increased so that the temperature rises steadily to 200°C over the next hour. Most flavour components are completely eluted in two and a half hours. The column temperature is varied so that the more volatile components which are eluted quickly are spread out evenly on the chromatogram, and the less volatile components emerging more slowly later are concentrated into sharp peaks at the higher temperature. In this way, the whole range of components are eluted to give one chromatogram (*Figure 3*). A peak does not necessarily contain a single component, but is more likely to be a mixture of two or three different compounds. One stationary phase alone cannot separate completely the mixture of compounds found in fruit flavours, which usually include alcohols, aldehydes, ketones, esters and occasionally hydrocarbons. The peaks are collected separately from the silicone-oil column and those which are shown to be mixtures by infra-red spectroscopy, are re-chromatographed on a different

above 100°C because the glycol begins to volatilize from the *Celite* at these temperatures and contaminates the fractions collected. Components which emerge in the higher temperature range of the silicone oil column are re-chromatographed on a polyester type of stationary phase, *e.g. Reoplex 400*, at column temperatures up to 150°C.

Experience often enables the operator to predict what a particular component is likely to be, and the use of two or more different stationary phases can confirm the identity of a component. A pure sample of the known substance, if available, is run on the same stationary phases under exactly the same conditions as the unknown, and if the known compound coincides with the unknown on all the columns, then the two are almost certain to be identical.

Infra-red and Mass Spectrometry

The amounts of each component or mixture of components eluted from the gas chromatography column are usually too small to apply the classical chemical methods of identification. The techniques of infra-red and mass spectroscopy are invaluable aids to identifying such small samples. The individual fractions are collected in a special trap attached to the outlet of the detector. It consists of a double U tube made from 2 mm bore glass tubing, shaped to fit into standard 1 pint dewar flask, and is fitted with a small ground glass stopper at each end.

The dewar is filled with crushed solid carbon dioxide and the trap is attached to the detector outlet by a short piece of silicone-rubber tubing just before the required component emerges. As soon as the component has been eluted, the trap is removed and stoppered immediately. A number of collections of the same component from successive chromatographic separations are made in the same trap until enough for infra-red analysis has been collected. Infra-red analysis often provides immediate identification, but failing this, the spectrum usually gives information about the type of compound present, *i.e.* whether it is an alcohol, ketone, aldehyde, ester or an acid, or whether it is saturated or unsaturated, aliphatic or aromatic. Mass spectrometry requires much smaller samples, and gives the exact molecular weight and information on the structure of the molecule itself. Combination of the gas chromatographic and spectroscopic information is usually enough to reduce the number of possibilities for a component to two or three compounds at the most, and the component is finally identified by comparison with pure samples of these compounds.

Paper and Column Chromatography of Derivatives

Gas chromatography is certainly the quickest and easiest way of finding out how many components there are in a mixture, but it is not the only way of separating the components of a flavour. Chromatographic separations of derivatives of the different classes of compounds have been achieved for strawberry flavour[6] using columns of silicic acid though not all the fractions could be identified.

It is well known that compounds such as aldehydes, ketones, alcohols and esters are important in the composition of the flavour of most fruits, and these groups of compounds can be separated by treating the liquid mixture with the appropriate reagent for each functional group. Carbonyl compounds are precipitated as the 2,4-dinitrophenylhydrazones which are separated by a combination of column and paper chromatography. Alcohols are converted into the 3,5-dinitrobenzoates which are also examined by paper chromatography. These derivatives can be separated and identified by comparison with known derivatives by using two or more solvent systems. The carbonyl derivatives are also separated on columns of alumina and magnesium sulphate to yield enough material for ultraviolet spectroscopic examination of each fraction. This will differentiate between saturated and unsaturated aldehydes, ketones, keto-esters and di-carbonyl compounds. These alternative methods of separation and identification of groups of compounds are a useful addition to the gas-chromatographic technique for confirming results already obtained, and for quickly locating the position of the known compounds on the gas chromatogram.

The contribution of each group of compounds to a particular flavour can be judged by selective removal of the group from the original mixture. An interesting sequence of changes occurs when groups of compounds are removed from concentrated strawberry flavour. The liquid concentrate has a strong, almost pungent, fruity odour. This pungent odour disappears when the carbonyl compounds are removed, leaving a pronounced ' soap-perfume ' odour. Removal of the alcohols causes the soap smell to disappear, and the residue, consisting mainly of esters, has a pleasant odour of strawberry jam. The esters, therefore, provide the basic odour of strawberries, the carbonyls and alcohols add various ' notes ' of their own, and the complete blend gives the ' fresh ' strawberry aroma.

When all the components of a flavour have been identified, it should be possible to reconstitute the complete flavour from the synthetic components. In practice, this is seldom possible. The relative proportions of each component can be calculated from the gas chromatogram, but when isolated from the natural material these are pure compounds. Synthetic compounds usually contain traces of impurities or other isomers which are difficult to remove, and their presence can cause marked changes in a delicately balanced flavour. The flavour chemist, however, can use the knowledge gained from such investigations to help him select those compounds which are readily available and, in the right combination, give to the flavour the ' boost ' which is so much sought after today.

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ACOUSTIC PUMP

T. M. DAUPHINEE

Applied Physics Division, National Research Council, Ottawa, Canada

A simply constructed air circulating pump powered by a loudspeaker is described. The pump has no moving parts other than the speaker cone and can operate from room temperatures to below liquid air temperatures at efficiencies equal to or better than those of conventional blowers.

SEVERAL years ago the writer gave a short description[1] of an acoustic pump in which a small loudspeaker was used for the circulation of air or other gases where no particular pressure head was required. The pump, which was an accidental outcome of an entirely different experiment, has had a number of applications in our own and other laboratories, and its novel approach to the gas circulation problem appears to have attracted enough interest to justify a more detailed description of its performance and possibilities.

The basic idea of the pump, which operates on the same principle as the so-called ' acoustic wind ', is illustrated in *Figure 1* and a picture of a small one such as has been used a number of times in our laboratory is shown in *Figure 2*. The construction is simplicity itself—the loudspeaker is mounted against a baffle (*a*) which has a hole in it into which a short length of tube (*b*) is fastened. The power is supplied at mains frequency by a small filament transformer. Dimensions of the tube are not at all critical—it is difficult to construct a pump that will not work at all—but much the best performance is obtained by operating reasonably close to the optimum, *i.e.* resonant, conditions. In the case of the 3 ohm, 5 in. speaker used for the pump shown the tube is about 2·5 cm long and 2 cm I.D.

When the power to the voice coil is turned on a stream of air of considerable velocity is projected straight away from the end of tube (*b*). If this stream is directed into the mouth of another tube (*c*), of fairly large diameter, it will entrain very substantial amounts of additional air, and total air flows of hundreds of litres a minute can then be maintained down the larger tube for the expenditure of a very few watts of power. This flow can be raised to thousands of litres through the use of larger, high efficiency speakers in place of the 5 in. one.

The mechanism by which the pump works is as follows: each time the speaker diaphragm moves forward it expels air through tube (*b*). This outgoing air has a considerable momentum component directed away from (*b*) as a result of the high velocity required to pass the whole volume displaced by the diaphragm through the relatively small aperture. The subsequent intake pulse draws in air without preference of direction and this in effect means air from the sides, which has no momentum component away from the tube mouth. The net result of the diaphragm action repeated 50 or 60 times per second is a relatively high velocity pulsing stream of air having a volume roughly equivalent to the total volume displacement of the speaker cone and projected straight away from the tube opening. When this jet is directed into the larger tube (*c*) (*Figure 1*) the normal viscous and turbulent drag processes bring about the establishment (in a comparatively short distance) of a normal velocity distribution across the tube with several times the volume of air that is contained in the original jet passing down the tube at much lower velocity.

Some details of air flow around the pump opening are illustrated by means of light paper strips in *Figure 3*. The strongly oscillatory movement of the air near the pump opening results in a large amplitude of the motion (about 5 cm) of a streamer held across it, while the strips attached at the outer edge of the baffle are pulled towards the aperture by the incoming air. The strips held in front of the aperture stream away from the speaker and flutter violently in the strong outgoing jet which provides the driving momentum of the system.

The entraining process described above actually represents a reduction of the efficiency of the system, since it is momentum that is conserved rather than kinetic energy. In the simplest case we would have a rate of transfer of momentum down the tube given by

$$Mv = K$$

where M is the mass of gas moved per second; v is the velocity, and K is a constant. Also, if ρ is the density of the gas and r is the radius of the tube

$$M = \pi r^2 \rho v$$

Elimination of v gives

$$M = (\pi r^2 \rho K)^{1/2} \propto r$$

The kinetic energy in the gas stream is therefore

$$K.E. = \tfrac{1}{2} Mv^2 = (K^3/2\pi r^2 \rho)^{1/2} \propto 1/r$$

Maximum efficiency is thus obtained by working into a tube about the size of the original jet, but for the greatest air flow a large tube is required.

Even in the best circumstances the efficiency of conversion from electrical energy to kinetic energy of the circulated gas is low. The power to the voice coil of the 5 in. speaker of *Figure 2* runs between 1 and 3 watts and represents an overall efficiency of a few tenths of a percent. However, one must remember that poor efficiency is a characteristic of small air circulation systems in general and both the gas delivery and the efficiency of this pump compare very favourably with 3 to 4 in., 1800 rev/min centrifugal blowers of the conventional types.

A tremendous improvement in efficiency and performance was achieved with the pump shown in *Figure 3* which is made up of a high quality 12 in. speaker (*Electrovoice SP12*-16Ω, 25W) mounted against a 6 mm *plexiglass* plate with a 7 cm hole in it, but no tube. Running at 13 W, 60 ~ (half its nominal power but about as much as could be run continuously), this pump delivered 1450, 3800 and 7700 l./min (55, 140 and 285 cfm) into short 6·5 cm, 15 cm and 30 cm tubes respectively. The corresponding operating efficiencies were 7, 4 and 2 per cent. Conventional blowers would normally require at least 50 watts to match this performance. One might note that air flow into the 6·5 cm opening
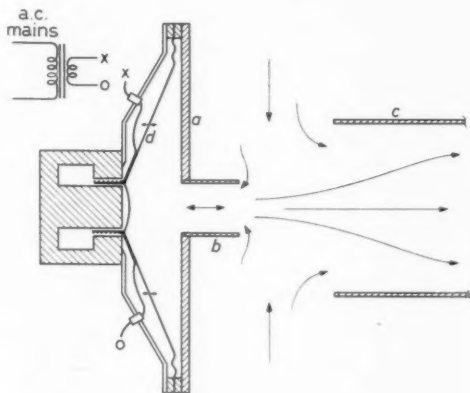

Figure 1. The principle of the acoustic air pump

located about 5 cm in front of the pump aperture was almost double the volume displacement of the speaker cone. There is, therefore, very considerable entrainment even under these conditions.

It might be thought that a pumping system which is feeding definite pulses of air would create disturbing amounts of noise and make the pump unsuitable for use in inhabited rooms. However, this does not turn out to be so, particularly in the case of
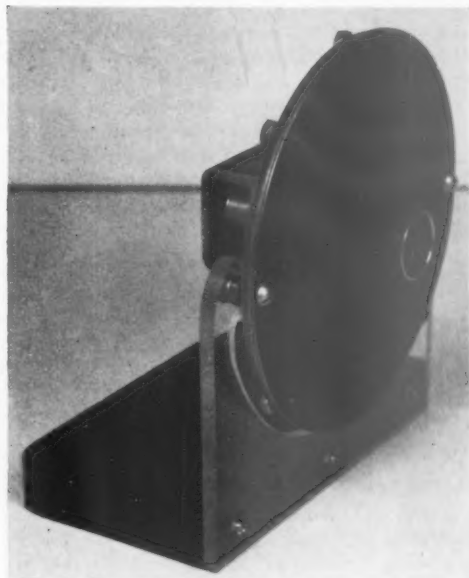

Figure 2. A pump made from a 5 in. loudspeaker

smaller pumps. In the first place, use of mains frequency places the fundamental tone well towards the lower limit of hearing where ear response is very poor. Secondly, small speakers which are not mounted in large area baffles are rather inefficient sound radiators at low frequencies with radiation from the back tending to cancel that from the front. Thirdly, since the tube diameter-to-length ratio has been chosen to give a flat resonance at mains frequencies the 50 or 60 cycle note tends to be quite a pure tone with few harmonics which would, of course, be much more audible. The overall result is a soft and unobtrusive hum which is not at all disturbing. If the speaker is overdriven or the voice coil scrapes the magnet the higher harmonics appear and the tone becomes a much less attractive and more penetrating buzz. The speaker also tells one immediately if there is any audio frequency disturbance on the line such as may be caused by power

drills and the like, but these high frequency components which radiate chiefly from the back are easily filtered out if they become troublesome. On the other hand it is quite feasible to superimpose music or speech on the pumping frequency without affecting the pumping action. The 12 in. pump gave appreciably more noise in higher harmonics than the 5 in. unit, most of it off the back as before. This was to be expected from a full range speaker but a rigid cone woofer would presumably be much quieter.

If the system through which the air is to be circulated contains narrow tubes it will be desirable to get maximum pressure by reducing the size of the tube (c) of *Figure 1* until it just covers the jet from the nozzle (b). When this is done driving pressures of

Figure 3. A pump made from a good quality 12 in. speaker with streamers showing details of the air flow

1 to 2 cm of water can be obtained although at the expense of a considerable reduction of the pumping rate. Greater pressures still can be obtained by the use of two speaker pumps operating in antiphase into the same tube opening or with high pressure horn driving units.

The acoustic pump as described has a number of additional characteristics not possessed by the conventional fan and centrifugal blowers which are more commonly employed. One of the most useful arises from the fact that there are no sliding parts so that no lubricants, which would freeze at low temperatures, are required. This means that the pump can operate quite happily at temperatures down to and below that of liquid air. In fact the lowered resistance of the copper wire of the voice coil and the increased density of the gas result in a quite substantial increase in efficiency. *Figure 4* shows a pump operating with the voice coil immersed in liquid air. The jet was made visible by pouring liquid air over the whole unit and into the nozzle.

In our laboratory this ability to withstand very low temperatures has been utilized for stirring low temperature air baths; these are used in the calibration of thermometers which cannot be immersed directly in bath liquids. One arrangement which we have found to be very convenient and easy to control is shown in *Figure 5*. The speaker (s) is placed in the bottom of a wide-mouthed dewar flask with an insulated lid. The tube (c) is mounted from the pump baffle (a) and the thermometers to be calibrated (T_x) are inserted into (c) along with the standard thermometer (T_s). Heating is provided when needed by a heater coil (h_1) in the space outside the tube, and to some extent by the voice coil power dissipation. Cooling and temperature control are accomplished by means of the cold gas outflow from a closed dewar containing liquid nitrogen and with a heater (h_2) immersed in the liquid to give an adequate and variable evaporation rate. Very quick cooling without thermal shock to the thermometers may be brought about by pouring a small amount of liquid nitrogen down the side of the dewar into the space around the voice coil. The small heat capacity of this system makes it particularly suitable for quick readings of moderate precision.

The writer has also been informed that a small pump unit has been used at 30,000 m altitude in a radiosonde balloon to circulate air through a gas analysis apparatus.

A second useful feature results from the use of a permanent magnet in the speaker so that a.c. fields are confined to those of the voice coil itself which has no iron and few turns. These fields are orders of magnitude less than those of a conventional a.c. motor and are therefore much less likely to cause electrical disturbances. Because of this it has been possible to use corner mounted speakers to circulate air in thermostatted instrument boxes even

Figure 4. A small (5 in.) pump with the voice coil at liquid air temperatures

lation of corrosive gases in reaction systems. The only requirement for work at atmospheric pressures is the ability to put a protective coating on the speaker cone or the availability of a thin flexible diaphragm which can be mounted between the speaker cone and the front plate, and which is inert to the gas being circulated. Both polythene and thin stainless steel diaphragms have been used for this purpose (the latter was quite noisy) and there does not appear to be any reason why noble metal or glass films, possibly plated or sprayed onto other material, could not be used as well. Operation at other than atmospheric pressures introduces a number of additional problems since the diaphragm cannot stand any appreciable pressure differential across it. This difficulty can be overcome by using in the place of the speaker cone a bellows strong enough to withstand the pressure and driven by a push rod and cam or a solenoid. There is a considerable loss of efficiency in such a system over the simple speaker arrangement; however in the circulating of corrosive gases we are usually concerned with circulation rate, not efficiency—and the
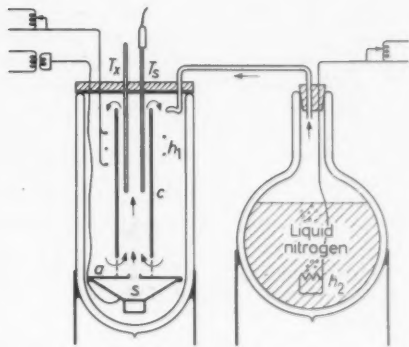
Figure 5. An air bath for calibration of thermometers at low temperatures

where a.c. pickup must be kept very small. Corner mounting of the speakers allowed quite efficient utilization of space. It is, of course, necessary to leave an outlet for the air behind the speaker cone; in this case a slot at the edge of the box directs the exhaust pulse from the back in a direction that reinforces the main flow from the nozzle. One such circulation system was in continuous operation for two years with no sign of deterioration. The two speakers were connected in antiphase so that vibration inside and noise outside were held to a minimum.

A third advantage results from the fact that the construction of the pump allows a complete barrier between the driving coil and the pumping region without any moving shafts which would require sealing for the handling of gases other than air. This allows the pump to be adapted for the circu-

gas handling capability of this pump is at least an order of magnitude greater than that of most other closed system circulators.

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PRODUCTION OF VACCINES

J. UNGAR

Glaxo Laboratories Limited, Greenford, Middlesex

DR UNGAR describes methods of producing the different types of vaccine from aerobic and anaerobic bacteria and from viruses, and also the large-scale production of organisms for vaccine production. This is the fourth article on the *Biochemical Engineering* series.

SINCE Jenner discovered the use of cowpox vaccine to protect against smallpox, the medical and veterinary professions have learned that one of the most important means of preventing infectious diseases is to use an effective vaccine. Depending on the cause and nature of the disease the protection is aimed either against the micro-organisms, *e.g.* the bacteria causing typhoid fever or whooping cough, or against their toxic products (toxins), as in dipthheria or tetanus. For reasons of convenience and safety, it is desirable to issue ' killed ' immunizing products, generally known as vaccines, the term adopted since Jenner's use of vaccinia virus—*vacca* (Latin) means cow. There are different methods of killing micro-organisms—chemical (antiseptics), thermal or physical (ultraviolet light, ultrasonic waves, x-rays). Sometimes, however, treatment by any of the above-mentioned means will destroy not only the viability of the micro-organism but also its immunizing power (antigenicity). In these instances it is essential either to use a live vaccine prepared from micro-organisms closely related to the causative agent of the disease or to develop a less virulent strain and use it for vaccine production. Depending, therefore, on the type of the disease to be protected against and on the properties of the infective organism, there are three types of vaccines: (*1*) killed bacterial or viral suspensions; (*2*) inactivated toxins (toxoids); (*3*) live vaccines.

The method of producing the vaccine will vary accordingly. It should be mentioned that considerable efforts are continuously being made towards isolating pure antigenic fractions from micro-organisms and have already shown promising results (*e.g.* in whooping cough, plague, anthrax).

The manufacture of vaccines has been helped by the development of techniques for large scale fermentation in industrial mycology and antibiotic production. Continuous culture methods, studied primarily for other purposes, gave rise to attempts to use this method in the production of vaccines.

Vaccines are usually issued as suspensions in isotonic saline. The antigenicity can be increased by adsorption of the toxoids on mineral carriers (*e.g.* diphtheria, tetanus) or suspending the vaccines in oil-in-water emulsions, as is done for a number of prophylactics used in veterinary medicine (erysipelas and anaerobic vaccines). It is also possible to increase the effect of toxoids by combining them with bacterial vaccines.

Below some of the methods used in preparing vaccines from micro-organisms are briefly discussed.

According to the growth requirements and the biological properties of the micro-organism, we can classify the different vaccines into three groups: (*1*) from aerobic bacteria; (*2*) from anaerobic bacteria; (*3*) from viruses.

Aerobic Vaccines

To prepare killed vaccines the bacteria employed are usually derived from virulent strains that are closely similar in antigenic properties to those found in natural infections. After isolating them and determining their protective properties, they are maintained as freeze-dried cultures. This ensures their viability without loss of essential protective antigens. The freeze-dried strains provide the initial cultures for vaccine production.

In some diseases, effective vaccines may be prepared from a single strain, whereas in others several strains are employed. In whooping cough, for example, all freshly isolated strains of *Bordetella pertussis*, the causative organism, constitute a single antigenic type; provided the subsequent processes involved in vaccine production do not destroy the antigenicity of the organisms, a vaccine prepared from one selected strain will protect against others of the same species. Frequently, however, continuous subculture of such strains on laboratory media results in loss of virulence and antigenic properties, and such strains have then become valueless for the preparation of effective vaccines.

Examples of killed vaccines that contain a multiplicity of strains are T.A.B. vaccine, which should contain the 'O' somatic, the 'H' flaggellar and the ' Vi ' antigen of *Salmonella typhi*, and the somatic antigens of *S. para* A and B. Such vaccines are prepared from the so-called smooth strains of the relevant species. Similarly cholera vaccine is prepared from the serological O-type of *Vibrio*

cholerae, Inaba and Ogawa, and should contain the full complement of 'O' antigens specific to each strain. When several types or species of bacteria exist within a group of organisms, such as those causing haemorrhagic septicaemia, the preparation of a vaccine must be based on knowledge both of the antigenic types prevalent in the area in which the vaccine is to be used and of the species of animal to be immunized.

Living bacterial vaccines usually consist of a single avirulent strain that has retained its protective antigenic properties. Those used for the preparation of BCG vaccine, *Brucella abortus* (S19) vaccine and anthrax vaccine have been selected and attenuated by frequent laboratory culture. Vaccines prepared from such strains may be aqueous suspensions or preferably freeze-dried.

For the production of bacterial vaccines, the freeze-dried cultures of the relevant bacteria are grown on solid or liquid media and examined for purity and specific cultural and serological characteristics; they are then used as inoculum for bulk production. When a solid medium is required for this purpose, standard *Roux* flasks are suitable containers. When liquid medium is used, the growth vessels may be bottles holding up to 20 litres or metal or enamel lined vessels designed and installed for sterilization and growth under controlled conditions *in situ*. With each organism the formulation of the growth medium, the duration of growth and such physical factors as pH and aeration need to be standardized to provide optimal potency. Frequently one or other of these factors in the conditions required for growth may be varied without detracting from the potency of the vaccine. Thus pertussis and typhoid vaccines may be produced on either solid or liquid medium, but when possible liquid medium is used, because it is more economical and convenient. Other vaccines, for example those against swine erysipelas and leptospira, are made from organisms grown exclusively on liquid medium. The former bacterium readily undergoes variation to the rough avirulent form on solid medium, and leptospira develops only slowly and unsatisfactorily on solid medium. *B. pertussis* used to be grown on Bordet-Gengou medium containing whole sheep-blood (*Figure 1*). Later it was found that the blood could be replaced with charcoal, the object being to adsorb inhibitory substances from the medium. Later still, a suitable liquid medium was formulated, containing hydrolysed casein, as a source of nitrogen, along with salts, starch and yeast extract. Commercial casein is a satisfactory starting material. This is hydrolysed to amino acids by prolonged refluxing with 6N HCl,

and removal of most of the excess acid by vacuum distillation. Substances that might otherwise inhibit growth, *e.g.* traces of fatty acids, are removed by adsorption on charcoal.

Figure 1. Characteristically glistening colonies of B. pertussis on Bordet-Gengou medium

Such a medium used for static cultures supports the growth of *B. pertussis*, but the rate of multiplication of the cells is slow, seven to ten days being required to provide cultures suitable for vaccine production. Agitation and aeration, provided by shake flasks, greatly increases the rate of growth. A more convenient method is to employ large bottles rolled at a sufficient speed to provide turbulence in the medium. Provided careful attention is given to pH control, suitable cultures are then obtained after 48 hours growth. A further advantage of this method is that sterility problems are eliminated, since no stirrer glands are needed. Further, when it is necessary to use several strains of a particular organism, each individual strain may be grown in a separate container, the resulting cultures being blended after inactivation.

When growth of the bacteria has proceeded for a suitable period they are killed, if necessary, and separated from the culture medium by centrifugation or, when solid media have been used, by washing them from the agar surface. Before separation the cultures may be examined serologically and microscopically. Thus with cultures to be used for the preparation of plague vaccine, it is essential that the cells should be fully encapsulated. Similarly, with anthrax spore vaccine, complete sporulation of the cultures is essential. When killed vaccines are required, the inactivation is accomplished by mild heating at 56°C or by treatment under controlled

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conditions of pH and temperature with formalin, phenol or thiomersalate; this involves no destruction of antigenicity. The preparation of the vaccine is completed by resuspending the organisms in the desired menstruum to a standardized strength, such as to comply with any official standards for safety and potency.

Purification of bacterial vaccines, other than separation of the cells, is not usually practised. Isolation of the active fractions involves disintegration of the cells. This has been performed on pertussis cells by means of ultrasonic vibration and subsequent adsorption of the specific protective antigen on red-cell stroma. Vaccine prepared in this manner was effective in preventing whooping cough amongst susceptible children.

Purification methods can be readily applied when the protective antigen can be prepared extracellularly, diphtheria toxoid providing a good example. The lethal toxin produced by the diphtheria organism can be prepared by growing the bacteria, Park Williams 8 strain, in a liquid medium. Static cultures in Mueller's semi-synthetic medium give high titres consistently. More recently, toxin has been produced in stirred cultures growing in large volumes of digest medium. After removal of the organisms, the toxin is converted to toxoid with formalin. This may then be purified to remove non-specific protein by fractional precipitation or by ultra-filtration or by both. Purified diphtheria toxoid prepared in this way provides a safe and effective antigen, whose potency can be accurately controlled. Its effectiveness may be enhanced by adsorption onto small quantities of aluminium phosphate or by mixing it with pertussis vaccine, to which tetanus toxoid may also be added, thus providing simultaneous effective protection against all three diseases.

Anaerobic Vaccines

Clostridia are responsible for a wide range of diseases in human beings and domestic animals. The diseases fall broadly into three categories: (*1*) wound infections, resulting in gas gangrene or tetanus; (*2*) food poisoning, particularly that caused by *Cl. botulinum*; (*3*) enterotoxaemic conditions, sheep being extremely susceptible.

Formalin-killed whole cultures were used in early attempts at active immunization, but it was found that the inclusion of the bacterial cells had little advantage except in the disease of cattle and sheep caused by *Cl. chauvoei*. Cell-free toxin suitably detoxified to prevent loss of antigenicity is now generally used.

Preparation of highly antigenic toxin is dependent on certain fundamental factors: (*1*) selection of satisfactory strains of *Clostridia*; (*2*) cultivation of such strains in a suitable medium, which, because of their anaerobic nature, needs to be deep liquid and of a satisfactory oxidation–reduction potential; (*3*) use of batches sufficiently large in volume to make production economic.

In large scale production it is convenient to use batches of 250 or 500 litres of medium, distributed in 15 or 20 litre reagent bottles. The medium is normally sterilized in the autoclave and used immediately it has cooled to incubation temperature. It is however, possible, to sterilize the medium by filtration, but chemical reducing agents, such as sodium thioglycollate or cysteine hydrochloride, must then be included.

Suitable seed cultures are prepared and used in their most actively growing phase to inoculate the batch, which is then incubated at the appropriate temperature for the necessary time. The length of incubation varies from organism to organism; for example, *Cl. welchii* requires only 18–24 hours incubation, whereas *Cl. tetani* requires at least six days.

Samples are then taken and checked for toxin level, *in vitro* and *in vivo* combining-power tests being carried out with a specific antitoxin. Harvesting of the batch usually involves first removing the bulk of bacterial cells by passing it through a centrifugal separator and then filtration through a sterilizing filter press. Formalin is added to the toxin, the pH adjusted and batch converted to toxoid by incubation at 37°C until *in vivo* testing shows the contents of each container to be non-toxic.

The toxoid is then processed into finished vaccine and may be immediately precipitated by addition of alum. It is, however, preferable first to remove any residual ingredients of the medium, as these are likely to provoke unpleasant reactions if injected. Purification is normally done by fractional precipitation at 4°C with ammonium sulphate. The precipitated toxoid is collected, redissolved in buffered saline, freed from residual ammonium sulphate by dialysis at 4°C against distilled water and then resterilized by filtration. *In vivo* and *in vitro* checks for antigenicity are carried out and the toxoid is diluted to final vaccine strength with buffered saline. Immunological products for human use as a rule take the form of the plain purified toxoid, *e.g.* tetanus toxoid. For veterinary prophylaxis it is usually considered preferable to combine the toxoid with an adjuvant, such as aluminium hydroxide. This enhances the antigenic response in a way similar to the alum precipitation mentioned earlier.

The media used for cultivation of *Clostridia* are normally protein hydrolysates of high nitrogen

Figure 2. (Left) Inoculation of fertile eggs with influenza virus; (Right) Harvesting the virus fluid from the eggs

content, usually prepared by enzymatic digest of meat, e.g. horse or ox flesh. Semi-synthetic media are, however, being used in increasing quantities, especially as purification of toxoid prepared in such media is much simplified.

Continuous culture techniques may also be used, and STERNE et al.[1,2] have described such techniques for Cl. botulinum and Cl. chauvoei in cellophane bags, a toxin of high titre being obtained from Cl. botulinum.

Much attention is being given to eliminating the problems involved in handling large batches of culture distributed in bottles, and THOMSON[3] has described a technique of cultivating Cl. tetani in 70 litre amounts of medium in a stainless steel tank. It is likely that in the near future it will be feasible to cultivate clostridial species in fermenter tanks in a manner similar to that used for antibiotic production.

Virus Vaccines

The important cultural difference between bacteria and viruses is that the latter need the presence of living cells for their multiplication. This requirement is provided by growing the virus in fertile eggs, in certain tissue cultures or in a suspension of living cells.

The method used in preparing an influenza virus vaccine illustrates the use of fertile eggs. A suitable virus seed is inoculated into the allantoic sac of ten day old eggs. After inoculation the eggs are incubated for a further two days. The eggs are now chilled before harvesting, to prevent bleeding from torn vessels with subsequent loss of virus. The allantoic fluid containing the virus is removed through the air sac by suction into suitable containers (Figure 2) and passed through sintered glass filters to remove particulate matter, and formalin is added.

Crude formalized allantoic fluid contains a large amount of unwanted egg protein in addition to the influenza virus; the former can be removed and the latter concentrated by centrifugation at high speeds. A Spinco centrifuge run at 21,000 rev/min (48,000 × g) for 60 minutes will sediment most of the virus present; for larger volumes of fluid a Sharples centrifuge run at 50,000 rev/min is used. The centrifuged virus is mixed to the desired concentration in the suspending fluid. Careful bacterial sterility and serological tests are done at all stages of preparing the vaccine, and the final product is carefully checked to see that it is antigenically active, as well as entirely safe to use.

The second method used in the preparation of virus vaccines, namely that with tissue cultures, can be illustrated by the preparation of poliomyelitis vaccine. The large scale production of this vaccine has depended upon four basic discoveries: first, that polio virus would grow in tissue culture cells; second, a medium able to support growth of these cells; third, the availability of antibiotics, particularly penicillin, to prevent bacterial infections; and fourth, that formaldehyde rendered the virus noninfective, though not affecting its antigenicity (Figure 3).

c*

The first stage in the manufacture of polio vaccine is to remove the kidneys from monkeys of suitable species and to prepare large volumes of tissue cultures. Two methods are used for growing monkey kidney cells. In the first, fresh monkey kidney tissue is chopped into small pieces and placed in bottles containing a shallow layer of nutrient fluid. The bottles are incubated while being rocked gently; during the next six or seven days cells grow out from the small fragments of tissue. The fluid is now removed from the tissue fragments, and fresh fluid is added, together with the polio virus strain chosen. The virus multiplies in the newly formed tissue cells and can be harvested after four days by drawing off the fluid from the bottles, leaving behind the degenerated cell fragments. The virus-containing fluid is filtered to remove any monkey kidney tissue and after testing is available for inactivation.

The method described has been employed in the manufacture of most of the polio vaccine prepared up to the present time, but an alternative method is being used on an increasingly large scale. In this method the monkey kidneys are chopped up and the fragments are treated with the digestive enzyme, trypsin, which breaks up the fragments into smaller clumps of cells. These are placed in bottles con-taining a shallow layer of nutrient medium. The bottles are incubated stationary, the cells settling on to the glass wall and growing into a continuous sheet in about one week. The method is now similar to the one first outlined. The fluid is removed and replaced by fresh medium containing the required strain of virus; after incubation for about four days, the fluid is harvested and filtered to remove cell debris. This method has the advantage that the amount of virus obtained from one monkey kidney is much larger than by the first technique, but in it there are one or two practical difficulties to be overcome.

Having obtained the virus fluid, the next step is to inactivate it. The fluid is first filtered through a bacteria-proof filter, to remove not only bacteria but also clumps of virus or cell debris that may escape inactivation. Formaldehyde is now added, and the virus fluid is held at 37°C. During the inactivation period, a second filtration is undertaken, to remove any clumps of virus that may have formed. After the virus fluid has been satisfactorily inacti-vated, it can be used for preparation of the final vaccine.

It should be stressed that at all stages in the manufacture of polio vaccine, extensive stringent control tests are undertaken. The potency of the
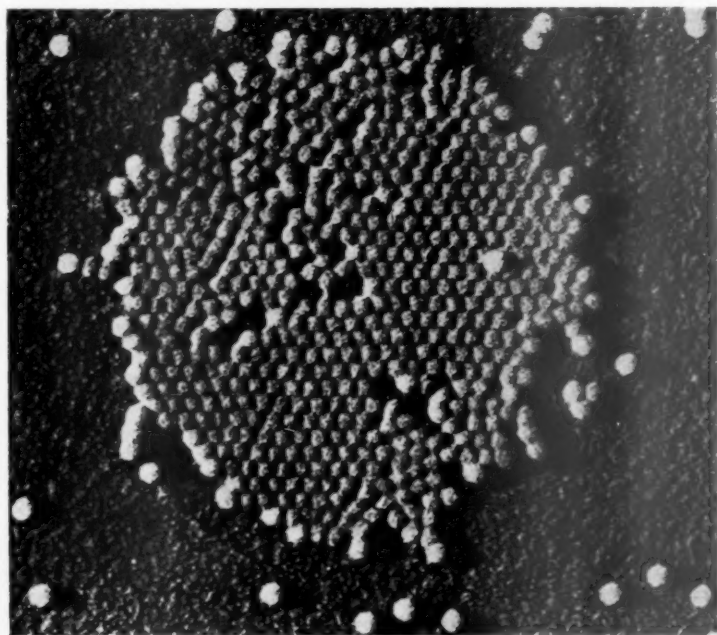

Figure 3. Electronmicrograph of poliomyelitis virus (× 110,000 × ½)

vaccine is controlled during manufacture by tests involving the responses of chicks and guinea pigs, and the final potency of the vaccine is measured on monkeys.

Large-scale Production of Organisms for Vaccine Production

The study of the large-scale culture of pathogens has been made in a number of laboratories, but the work has been concentrated on the culture and equipment rather than on the quality of the vaccine produced. BILLAUDELLE, HEDÉN and MALMGREN[4] reported the production of *B. pertussis* in 500 litre quantities, and other workers have indicated that good yields of diphtheria and tetanus toxin could be obtained in 80 litre vessels with ' vortex aeration '. In South Africa VAN DRIMMELEN[5] employed a 250 litre fermenter vessel for the growth of *Brucella abortus* Strain 19.

Most of this work referred to batch production, but some attempt has been made to use semi-continuous methods*. Reports have indicated that methods involving a dialysis tube system are suitable for producing *Brucella abortus*, *Cl. tetani* and *Cl. chauvoei*, and other workers have successfully grown *Salmonella typhimurium* and mycobacteria in continuous flow systems.

Any increase in the scale of a process emphasizes the mechanical risks and, in particular, the hazards of dispersal of infective aerosols and contamination of the culture. HEDÉN and MALMBORG[6] and ACHORN *et al.*[7] described equipment designed to meet this challenge. The necessary conditions can also be provided to secure little likelihood of the development of variants liable to upset the immunological response of organisms grown by continuous culture. *Salmonella typhi* has been grown in continuous culture with no apparent loss of virulence or immunogenicity, and STERNE[8] in culturing *Brucella abortus* used the residual cells in his system as inoculum for four to six succeeding batches. It has been established, however, that the physiological state of an organism is much more dependent on external factors in this type of system than by ' classical ' culture.

Inevitably the transfer to the larger scale brings the process into the field of biochemical engineering. Subjects which have already been studied for the major fermentation industry and which are applicable are:

(*1*) The sterilization of media which will avoid destruction of essential ingredients. This is a feature which is emphasized with the increasing

* See *Research* (1960) **XIII**, 257 (*Continuous Culture Process* by LUMB and WILKIN)

volume of cultures and frequently leads to the adoption of high temperature–short time methods.

(*2*) The sterilization of air for which virtually only one technique is now used—filtration through fibrous or granular media. It is essential to recognize that filter efficiency for fibrous materials is closely dependent on the air velocity and that the range of maximum performance may be narrow.

(*3*) Efficient aeration is not as difficult as for the filamentous organisms but foaming may be troublesome. ' Vortex-aeration ' and ' pulse-aeration ' are being used to overcome this.

(*4*) With a smaller problem presented by the necessary aeration, mixing demands are reduced and may be limited to maintaining uniform conditions in the culture.

(*5*) The optimizing of conditions for antigen production require more stable conditions and continuous pH control is being applied. This refinement leads eventually through medium reinforcement techniques to continuous culture schemes.

The maintenance of maximum antigenic potency frequently leads the purification techniques to a final freeze-drying. In this the suspending media, rate of freezing, ice sublimation rate, final moisture concentration, presence of air in the final container may all be critical and require study. Nevertheless plants are operating which handle many thousands of doses a day.

However there remains even today a belief that vaccine production is a relatively small scale operation and that ' plant ' scale working is unnecessary. It is clear that the increased emphasis on preventive medicine throughout the world will accentuate the demands for large quantities of vaccine. To meet these requirements it will be essential to improve available methods of vaccine production.

The illustrations are reproduced by courtesy of Glaxo Laboratories Limited.

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THE PHYSICAL CONSTANTS OF SEA ICE

DON L. ANDERSON

California Institute of Technology

The continuous phase changes taking place in the interior of sea ice make it a remarkable substance. All of the physical properties are extremely temperature dependent and are controlled by the quantity of brine in the interstices. The basic physical and thermal properties of sea ice are presented in tables and graphs; the apparently erratic behaviour is caused by precipitation of cryohydrates.

FOR a substance that comprises approximately 7·3 per cent of the earth's surface, sea ice has received remarkably little detailed study. MALM-GREN's[1] drift in the Arctic Ocean during the early years of the century led to a classic work which is still the standard reference on this subject. The recent increase in Arctic activities by aircraft, surface ships and submarines, and the possibility of obtaining fresh water from the sea by freezing, combine to make the study of sea ice a vital practical matter. The purpose of this paper is to present the results of recent calculations of the basic properties of sea ice made possible by new studies of its composition.

Ice, unlike most other natural substances, is never far from its melting point. This fact plus the volume increase upon freezing are responsible for many unique characteristics. A slight amount of salt has a profound influence, making sea ice quite distinct from fresh ice and even more remarkable in behaviour. Salts and gases are excluded from the ice lattice and concentrate between the ice crystal and the subcrystal units in brine cells and air bubbles. Consequently, sea ice must be studied as a three phase system. The brine cells, analogous to Tyndall figures in pure ice, accentuate grain boundary phenomena and control the behaviour and properties of sea ice. The amount and composition of the interstitial brine, and the size of the brine cells is determined by the temperature, salinity and thermal history of the ice, and the physical properties are affected correspondingly. Sea ice never becomes completely solid in its natural environment although brine is continually removed by drainage and by migration along temperature gradients, causing the ice to freshen continually.

Freezing of Sea Water

The nature and order of deposition of solids due to the freezing of sea water is quite different from the sequence of salt deposition caused by evaporation; RINGER[2], and NELSON and THOMPSON[3] have determined the order of formation of the major salts upon freezing sea water and the composition of the residual brine. The freezing point of sea water is the initial temperature at which ice is in equilibrium with water of the given salinity. Pure ice forms from normal sea water at temperatures below −1·8°C and continues until the resulting brine is in equilibrium with the environmental temperature. A change in temperature will melt or freeze ice so as to keep the brine in equilibrium. Sodium sulphate decahydrate is the first salt to precipitate in quantity starting at −8·2°C and continuing until approximately −23°C. Sodium chloride dihydrate begins to come out of solution at −22·9°C causing a large decrease in brine content at that temperature. Potassium chloride forms at −36°C and the dodecahydrate of magnesium chloride precipitates at temperatures colder than this. Calcium chloride hexahydrate forms at −54°C allowing most of the remaining brine to freeze. Calcium carbonate takes longer to reach equilibrium and precipitates unpredictably. Double salts such as $MgCl_2 \cdot KCl \cdot 6H_2O$ (carnallite) and $Na_2SO_4 \cdot CaSO_4$ (glauberite) may also form. Magnesium probably also appears as $MgCl_2 \cdot 8H_2O$, or $MgCl_2 \cdot 6H_2O$ depending on the temperature. These salts are the so-called cryohydrates and most of them exist only at low temperatures.

The freezing point curve for sea water is illustrated in *Figure 1*, the data are computed from ion concentration measurements of NELSON and THOMPSON[3] by adding the major ions in solution and multiplying by a correction factor to obtain the defined salinity. Uncertainties at the lower temperatures are indicated by the alternate paths followed in different experiments and are probably due to experimental departure from equilibrium. Each break in the curve corresponds to the precipitation of a new salt.

Although never determined directly, the phase relations are fundamental to all studies of sea ice since it is the heterogeneity and fluid content that control the properties. These relations can be computed from brine concentration measurements by solving mass balance equations for each ion. Of the

more than forty-four elements that have been detected in sea water, SVEDRUP[4], six ions (sodium, magnesium, potassium, calcium, sulphate and chloride) account for more than 99 per cent of the dissolved solids, making the task not so formidable. Because of the water of hydration the salt content of completely solid sea ice is greater than the salinity of its meltwater, although, because of drainage, the salinity of sea ice is always less than natural sea water. *Table 1* gives the composition of 'simplified sea water' containing only the six major ions, according to a formula of LYMAN and FLEMING, (SVEDRUP[4]). The total salinity is 3·254 per cent. The composition of the resulting completely frozen ice is 6·28 per cent solid salts, including water of hydration, and 93·72 per cent pure ice, assuming that all of the salt is retained in the ice, *i.e.* there is no brine drainage. Note that ice with this composition does not become completely solid until it has been cooled below the eutectic temperature of $CaCl_2 \cdot 6H_2O$, $-54°C$. Because of exclusion of salt in the freezing and aging processes a salinity of 0·3–0·5 per cent is

The solution of the mass balance equations results in the phase relations by weight, shown in *Figure 2*. Details of the solution are given in ANDERSON[6] and ASSUR[7]. Immediately evident from this curve is the rapid initial decrease in brine content after freezing

Table 1. Simplified composition of sea water and sea ice

Sea water (g/kg)					
Na_2SO_4	3·74	Na^+	0·53	SO_4^{--}	3·20
NaCl	22·38	Na^+	8·81	Cl^-	13·57
$MgCl_2$	4·75	Mg^{++}	1·21	Cl^-	3·53
KCl	0·63	K^+	0·33	Cl^-	0·30
$CaCl_2$	1·05	Ca^{++}	0·38	Cl^-	0·67
Salinity	32·54	ΣNa^+	9·34	Cl^-	18·07

Solid ice (g/kg)		$T(°C)$
$Na_2SO_4 \cdot 10H_2O$	8·44	$-8·2$
$NaCl \cdot 2H_2O$	36·15	$-22·9$
$MgCl_2 \cdot 12H_2O$	15·51	$-44·0$
KCl	0·63	$-36·0$
$CaCl_2 \cdot 6H_2O$	2·07	$-54·0$
Total Solids	62·80	

and the jumps due to crystallization of salts. The mechanical properties of sea ice can be qualitatively explained from this figure. For example, sea ice of 1·0 per cent salinity at $-2°C$ is essentially a mush containing 266 g of brine per kilogram of sea ice, and would not be expected to be very strong. Only one half this amount of brine remains at $-5°C$ and the ice is correspondingly stronger. Ice of 2·0 per cent at $-2°C$ is over half liquid and would be expected to have very little coherence. *Figure 3* shows the *volume* phase relations, which are more pertinent for many purposes, *versus* temperature and salinity of the ice. On this double log scale the brine content is almost linear with temperature down to $-22·9°C$ facilitating the formulation of analytic expressions containing brine content.

The *weight* and *volume* phase relations are tabulated in *Table 2* along with pertinent properties of the components (ρ_b, density of brine; ρ_i density of pure ice; β_w, brine content by weight; S, salt content by weight; β, brine content by volume; V_i, ice content by volume; V_s, solid salt content by volume). The brine and salt content by weight are proportional to the ice salinity and are only tabulated once. The volume ratios are only approximately proportional to salinity, so are tabulated for five typical values of ice salinity.

Newly formed sea ice can have salinities as high as 2·0 per cent, especially if frozen rapidly. Ice a few weeks old generally has a salinity close to 1·0 per cent. After several months under natural conditions the salinity has decreased to about 0·5 per cent,
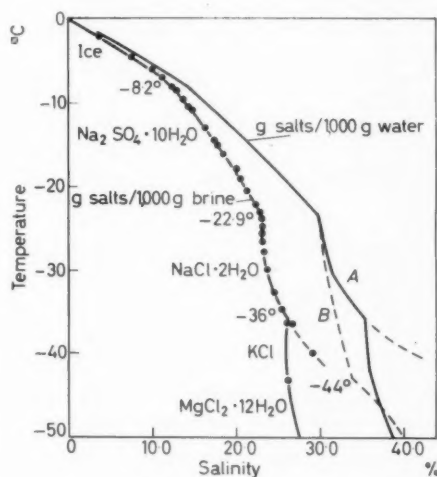

Figure 1. Freezing point curve of sea water brine showing the concentration of brine in equilibrium with ice versus temperature. The various solid salts are listed opposite the segment of the curve in which they are the dominant salt crystallizing. Dashed lines indicate alternate interpretations, or possible alternate paths of crystallization

more typical of sea ice. Therefore, a very small amount of 'impurity' causes the gross difference in behaviour and structure between sea and fresh water ice.
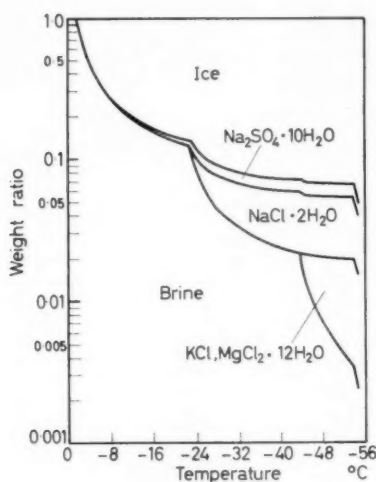
Figure 2. Phase relations, by weight of the major components in sea ice of salinity 3·254 per cent. The concentration and composition of the brine is continuously changing as the solids are removed

and 0·3 per cent is typical of sea ice near the end of its first year. Older pack ice can have salinities around 0·1 per cent and lower.

The density of air and void free sea ice can be easily calculated from the volume phase relations and is presented in *Figure 4* and *Table 2*. It is clear that the density of sea ice is quite temperature and salinity dependent. The unusual shape of the curve is, of course, due to the continuous phase changes taking place as the temperature is lowered. Unlike other substances, and indeed unlike its own components, the volume of sea ice *increases* as the temperature is lowered. This behaviour explains the absence of *thermal* cracks in sea ice sheets making it unlike lake ice in this regard. The density goes through two minima and the absolute minimum jumps abruptly at 0·6 per cent from $-14°C$ to $-26·5°C$. Because of the thermal and salinity profiles through an ice sheet the top may be contracting while the bottom is expanding, causing the stress–strain relations in a sea ice sheet to be complex. The numerical difference between the measured and theoretical values is the porosity. Voids or 'vapour figures' probably invariably form upon melting of the ice or upon crystallization of salts.
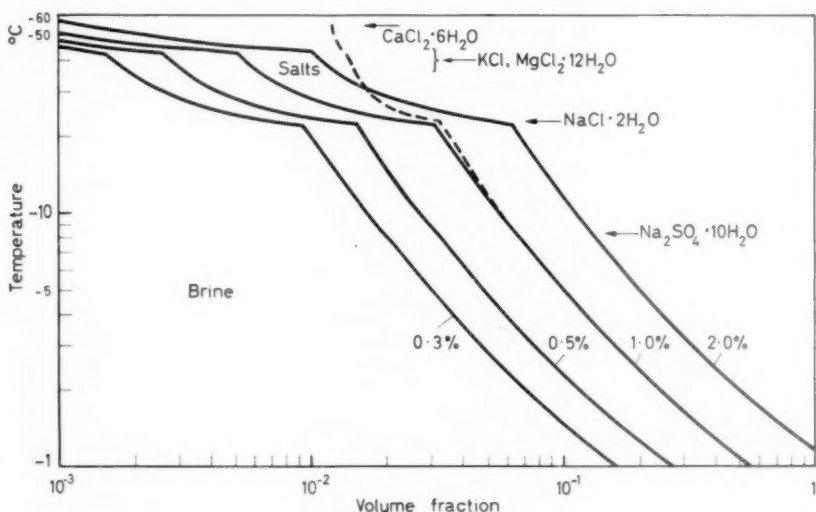

Figure 3. Phase relations, by volume, of sea ice of four typical salinities. The salinity decreases with age. The solid salt content is shown only for ice of 1·0 per cent; it is approximately proportional to salinity. The square root of the abscissa gives the approximate relative strength of the ice, and corresponding relations hold for most other physical properties

Table 2. Composition of sea ice

| T °C | 1·0% | | | | | | | 0·1% | 0·3% | 0·5% | 2·0% |
	ρ_b g/cm³	ρ_i g/cm³	β_w g/kg	S g/kg	β cm³/dm³	V_s cm³/dm³	V_i cm³/dm³	β cm³/dm³	β cm³/dm³	β cm³/dm³	β cm³/dm³
0	1·0276	0·9168	1000·00	0	1000·00	0	0	1000·0	1000·0	1000·0	1000·0
− 2	1·030	0·91711	266·07	0·00	244·0	0·0	756·0	23·8	71·7	120·2	503·2
− 4	1·058	0·91743	141·28	0·02	124·9	0·0	875·1	12·3	37·0	61·8	254·6
− 6	1·081	0·91773	100·12	0·04	86·3	0·0	913·7	8·5	25·6	42·8	175·3
− 8	1·099	0·91802	78·97	0·05	66·8	0·0	933·1	6·6	19·9	33·2	135·5
−10	1·115	0·91827	66·37	1·21	55·3	0·8	943·9	5·5	16·5	27·5	112·1
−12	1·130	0·91853	58·51	1·78	48·1	1·1	950·8	4·8	14·3	23·9	97·4
−14	1·144	0·91882	53·17	2·04	43·1	1·3	955·6	4·3	12·8	21·5	87·3
−16	1·156	0·91912	49·03	2·20	39·4	1·4	959·2	3·9	11·7	19·6	79·7
−18	1·168	0·91937	45·63	2·32	36·3	1·4	962·3	3·6	10·8	18·1	73·4
−20	1·180	0·91962	42·61	2·42	33·6	1·5	964·9	3·3	10·0	16·7	67·8
−22	1·190	0·91987	40·00	2·52	31·2	1·6	967·2	3·1	9·3	15·5	63·1
−24	1·201	0·92013	28·74	6·24	22·2	3·9	973·9	2·2	6·6	11·1	44·8
−26	1·211	0·92038	18·58	9·99	14·2	6·2	979·6	1·4	4·2	7·1	28·7
−28	1·221	0·92064	13·93	11·74	10·6	7·3	982·1	1·1	3·2	5·3	21·4
−30	1·229	0·92089	11·51	12·65	8·7	7·8	983·5	0·9	2·6	4·3	17·5
−32	1·238	0·92113	10·14	13·17	7·6	8·2	984·2	0·8	2·3	3·8	15·3
−34	1·246	0·92137	9·14	13·54	6·8	8·4	984·8	0·7	2·0	3·4	13·7
−36	1·255	0·92161	8·45	13·78	6·3	8·5	985·2	0·6	1·9	3·1	12·6
−38	1·262	0·92185	7·89	13·93	5·8	8·7	985·5	0·6	1·7	2·9	11·7
−40	1·270	0·92208	7·37	14·17	5·4	8·9	985·8	0·5	1·6	2·7	10·9
−42	1·277	0·92230	6·94	14·32	5·0	8·9	986·1	0·5	1·5	2·5	10·2
−44	1·284	0·92252	5·27	15·49	3·8	9·6	986·6	0·4	1·1	1·9	7·7
−46	1·290	0·92274	3·24	16·97	2·4	10·5	987·1	0·2	0·7	1·2	4·7
−48	1·297	0·92296	2·17	17·73	1·5	11·0	987·5	0·2	0·5	0·8	3·1
−50	1·303	0·92319	1·53	18·12	1·1	11·2	987·6	0·1	0·3	0·6	2·3
−52	1·310	0·92339	1·23	18·37	0·9	11·4	987·7	0·1	0·3	0·4	1·8
−54	1·314	0·92359	1·01	18·52	0·7	11·5	987·8	0·1	0·2	0·4	1·4

Table 3. Density of sea ice

| Temp °C | Salinity, per cent | | | | |
	0·1	0·3	0·5	1·0	2·0
0	1·0276	1·0276	1·0276	1·0276	1·0276
−2	0·9198	0·9252	0·9307	0·9447	0·9739
−4	0·9192	0·9226	0·9261	0·9350	0·9532
−6	0·9191	0·9219	0·9247	0·9318	0·9464
−8	0·9192	0·9216	0·9240	0·9301	0·9426
−10	0·9194	0·9216	0·9239	0·9296	0·9412
−20	0·9206	0·9225	0·9244	0·9292	0·9390
−22·9	0·9209	0·9227	0·9246	0·9292	0·9387
	0·9209	0·9227	0·9245	0·9290	0·9383
−25	0·9211	0·9227	0·9242	0·9283	0·9364
−30	0·9216	0·9230	0·9245	0·9281	0·9354
−35	0·9222	0·9236	0·9250	0·9285	0·9357
−40	0·9228	0·9241	0·9255	0·9290	0·9361
−45	0·9233	0·9247	0·9261	0·9296	0·9366
−50	0·9239	0·9252	0·9266	0·9301	0·9371

Figure 4 (right). Density of sea ice versus temperature and salinity, with pure ice drawn for reference. The light solid line shows the absolute minima; dashed line gives local minima. These curves can be used to determine air or void content
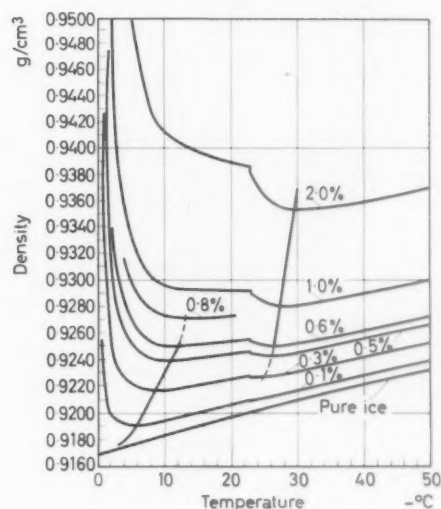
Calculation of the coefficient of thermal expansion illustrates in a striking way the anomalous behaviour of sea ice. The coefficient is nearly linear in most substances but, as illustrated in *Figure 5*, is seemingly erratic in sea ice. It varies over several orders of
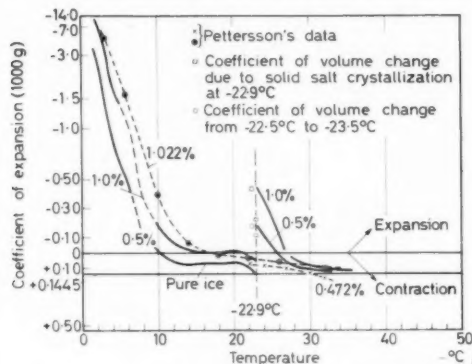

Figure 5. *Arctan of coefficient of volume expansion versus temperature and salinity for air and void free sea ice. Pure ice behaves almost linearly as do most substances*

magnitude and can be negative (expansion) or positive (contraction). Again, the volume of the ice is assumed to follow faithfully the volume variations of the components ruling out formation of either voids or internal pressures. The only available data, PETTERSSON[8], do not obey this restriction, but show general agreement.

In these calculations the density of pure ice was taken to be 0·91680 g/cm^3 at 0°C, which is the average of the best values in DORSEY[9] with the fifth decimal arbitrarily taken as naught. The densities at the other temperatures were computed from the coefficient of thermal expansion given by BUTKOVICH[10]. After the calculations were carried out it was discovered that BUTKOVICH[11] has also very accurately measured the density of single crystals of ice at temperatures near −3·5°C. In addition to his increased accuracy, Butkovich's densities are to be preferred because they were measured at temperatures other than the melting point of ice. The maximum measured at −3·5°C by Butkovich is 0·91728 g/cm^3, as compared to 0·91735 g/cm^3 which is computed from measured densities at 0°C. This indicates that the presence of liquid water has affected the measured densities near the melting
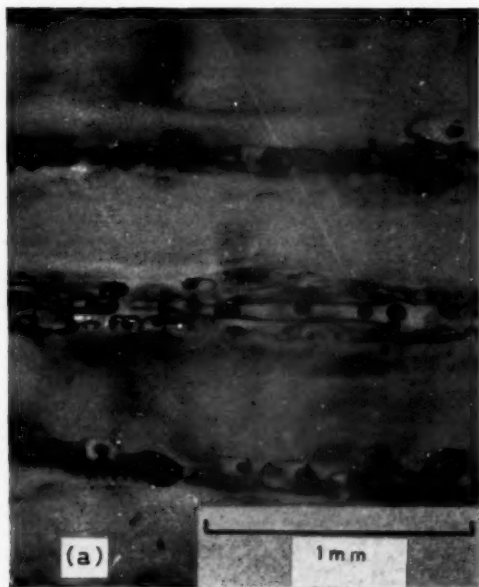

Figure 6. *Photomicrographs of horizontal sections of sea ice showing pure ice platelets separated by layers containing brine cells and air bubbles. The ice in* (b) *is colder than in* (a). *Schematic drawing of these relations is shown in Figure 7.* (*Courtesy American Geophysical Union*[12]; *photographs by* W. F. WEEKS)

point, a difficulty which plagues all measurements on ice. The error introduced in this way is, however, much less than other possible errors. The brine densities were extrapolated from refrigerant brine data, and a constant 1·5 g/cm³ was adopted as the density of the salt hydrates. If the phase relations are correct, the densities are accurate to four decimal places, sufficient for most purposes.

The Structure and Structural Properties of Sea Ice

Although sea ice is a heterogeneous mixture of varying amounts of pure ice, solid salts, air and brine, the arrangement is systematic enough to encourage a quantitative study of its behaviour. Such an attempt would allow meaningful extrapolation of the present meagre data, help fill in experimental gaps, and guide future experimentation. Two photomicrographs of sea ice are presented in *Figure 6*, illustrating the spatial arrangement of the pure ice platelets, brine cells and air bubbles. The spacing of the elements is controlled by the ice lattice and the brine–ice surface tension.

It was shown in an earlier paper (ANDERSON and WEEKS[12]) that the strength of sea ice is proportional to the amount of ice along the failure plane:

$$\sigma/\sigma_i \sim (1 - \beta_e) \qquad \ldots . (1)$$

where σ/σ_i is the strength of the sea ice relative to brine and air free ice at the same temperature, and β_e is the 'planar' porosity due to brine and air. For cylindrical brine cells and air free ice this becomes, in terms of brine content:

$$\sigma/\sigma_i = 1 - [2/(a\pi)^{1/2}]\beta^{1/2}; \quad a = l/w \qquad \ldots . (2)$$

where l and w are the spacing of the brine cells in the plane of the ice sheet along, and normal to, the c-axis, respectively, the axes of the cylinders being normal to the sheet. The symbol a then stands for a dimensionless structure ratio which depends on the arrangement of the brine cells. The relative strength therefore is proportional to the square root of the brine content, other factors (crystal structure, stress concentration) remaining the same. This has received quite satisfactory experimental verification. Temperature has both first and second order effects, controlling not only the amount of brine but the strength of the pure ice 'bridges' and the ability of the ice to maintain a stress concentration. If the ice is perfectly elastic the stress concentration around minute flaws will be approximately three in tension; this condition is probably approached in very cold, relatively pure ice, under rapid loading. In warmer ice the stress concentration changes due to the interference of stress patterns of adjacent flaws and the increased ability of the ice to relieve stress by flow and recrystallization. *Equation 2* can be

generalized to include the effect of stress concentration:

$$k(\sigma/\sigma_i) = [1 - (4\beta/\pi)^{1/2}] \qquad \ldots . (3)$$

where k is the relative ability of the test samples to maintain a stress concentration relative to the
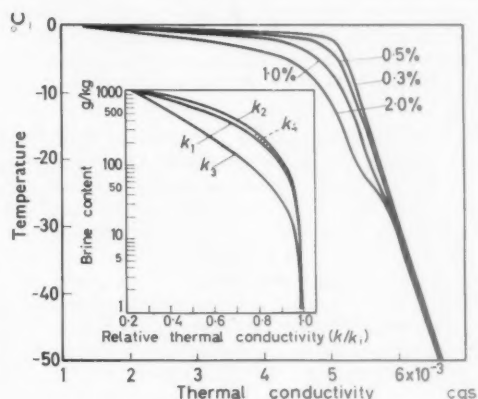

Figure 7. Computed thermal conductivity of sea ice versus temperature and salinity considering brine to be in isolated spherical cells. Inset shows conductivity relative to pure ice for four possible geometries of brine and ice

reference sample. If k is obtained by extrapolating measured strengths to zero brine content, then test conditions may be considered essentially identical and k is one. If the strength is referred to separate but similar tests on 'pure' ice, k will be slightly different from one, due to the differing ability of the sea ice platelets and pure ice to maintain a stress concentration. The presence of brine restricts the area in which the concentration may occur. If the strength is referred to absolutely pure ice such as may be measured on 'whiskers' k will be approximately three. The ability of sea ice to maintain a stress concentration probably increases in cold ice although the area over which the stress may be distributed increases as brine is replaced by ice and solid salts. In any event, the stress field is distorted and is only approximately that calculated assuming homogeneity and perfect elasticity. For these reasons strength tests on sea ice should be designed to cause failure away from any stress concentration introduced by the test itself.

Although strength is a smooth function of brine content it would be expected to increase abruptly at the eutectic temperatures of the various salts due to a sudden decrease in the amount of brine at these temperatures. Very cold sea ice probably approaches the strength of pure ice at the same temperature

although the difference in structure and possible greater plasticity presumably would have a slight effect. Under natural conditions young sea ice is generally only one third to one half as strong as fresh ice, but increases in strength as it freshens during subsequent winters. In general the strength varies over a wide range. Knowledge of the strength of ice is important in establishing and supporting scientific stations on Arctic pack ice and for the operation of aircraft, submarines and shipping in the Arctic Ocean.

Thermal conductivity is a property of sea ice that is fundamental to many studies in the Arctic Ocean but has not been measured in detail. It is important in studies of ice growth, deterioration and the general problem of heat transfer in Arctic regions. The relative thermal conductivity of sea ice can be computed approximately by considering the brine and ice to be thermal resistances arranged in series-parallel. Four different models have been computed, with the brine being (a) in isolated spherical bubbles; (b) in parallel cylinders, or parallel layers between ice platelets and the conductivity measured in the direction of the brine layers; (c) in parallel layers and the conductivity measured perpendicular to the layers; (d) in parallel cyclinders spaced according to measurements from photographs and conductivity measured normal to the axis of the cylinders. The thermal conductivity relative to pure ice at the same temperature for the four models is shown in the insert of *Figure 7*. The three most realistic models all give similar results, but the small effect of structure has important consequences. The actual thermal conductivity for ice of several salinities is computed from the spherical brine cell model, also shown in *Figure 7*. Again we see the large temperature effect especially on warm ice. The variability of the thermal conductivity has a pronounced effect on the growth rate of sea ice and the heat transferred between the ocean and the atmosphere at different seasons in the Arctic. The anisotropy of thermal conductivity will favour the crystal orientation that is observed *in situ* (*i.e.* horizontal *c*-axis, WEEKS[5]) although not necessarily control it. Lake ice can have either predominant horizontal or predominant vertical *c*-axis, while sea ice invariably has a predominant horizontal *c*-axis structure.

Thermal conductivity is difficult to measure because of the large amount of heat involved in phase changes and brine migration. If heat is introduced in the measuring process latent heat may be responsible for a loss of heat comparable to that carried away by conduction. To determine the magnitude of the effect we must know the latent and specific heat of sea ice, which are also very important in their own right. We will devote the next section to this calculation.

The dimensions and spacing of the brine cells vary considerably but can be analysed statistically. The platelet width, measured along the *c*-axis, is about 0·5 mm for pure ice, and for sea ice varies at least from 0·39 to 0·5 mm. Sometimes a brine layer is only insipient giving an apparently thicker platelet. As the planar brine layer becomes unstable it splits into cylinders of brine. Assuming cylindrical brine cells the geometric parameters can be conveniently related to brine content. In dimensionless form:

$$r/w = (l/w \cdot \beta/\pi)^{1/2} \qquad \ldots (4)$$

where r is the radius of the cylindrical brine cell, w is the platelet width, l is the average cell spacing along the brine layer, and β is the relative brine content by volume. In the photograph w averages 0·46 mm and l/w is about one half. These structure ratios are plotted in *Figure 8*. The average cell diameter in millimeters is approximately one half the value read from the abscissa, dependent on the platelet width measured or assumed.
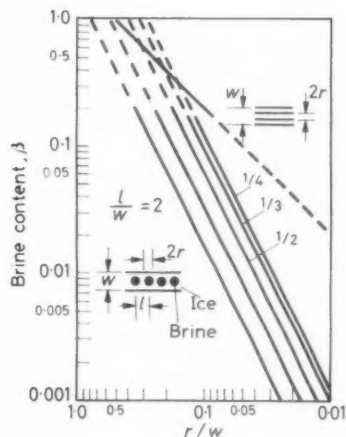

Figure 8. Structure ratios for planar and cylindrical brine cells giving dimensions and spacing of brine cells versus brine content and ice platelet thickness

For planar brine cells, such as exist in warm ice: $r/w = (\frac{1}{2})\beta$ where r is now one half the brine layer width. The minimum stable width of the brine layer is about 0·07 mm which occurs at a brine content of 0·152; a layer structure predominates at

higher brine contents, and a cylindrical structure is favoured below. These calculations are important in studying the permeability of sea ice to air and brine.

The direct way to verify the phase relations in sea ice experimentally is by use of calorimetry. This is the most pressing current need in sea ice research since the theoretical derivation of all the physical and thermal properties is based on a theoretical phase diagram deduced indirectly from data acquired for other purposes. However, the interpretation of the calorimetric results requires an accurate knowledge of thermal properties of the constituents; *i.e.* the latent heat of ice freezing from solution, the heat of crystallization of the salts, the heat of dilution of brine, and the specific heat of the ice, salts and brine. These data are also imperfectly known but could be obtained by calorimetry if the phase relations were known in sufficient detail. As a first step in this ' boot-strap ' operation we synthesized available data of the pure components into a theoretical melting curve and determined therefrom the

' specific heat ' and ' heat of melting ' of sea ice. Since the thermal properties of the components in combination are not the same as for the pure material, the theoretical melting curve will have to be modified by experiments, permitting more accurate values to be assigned to the constituents in combination. In any event the theoretical melting curve will be sufficiently accurate for thermal conductivity corrections, growth studies and Arctic Ocean thermal budget studies.

The heat required to raise the temperature of sea ice is expended in melting a certain amount of pure ice, dissolving salts (and diluting the brine) and raising the temperature of the remaining brine, ice and salts. In symbols:

$$\Delta H = \delta I \Delta H_i + \delta S \Delta H_s + (IC_i + SC_s + \beta_w C_b)\Delta T$$
$$\dots (5)$$

where ΔH is the heat required to raise the temperature by ΔT of a piece of sea ice whose average composition over the temperature range is

$$S + \beta_w + I$$

Table 4. *Thermodynamic properties of sea ice and components.* (*Based on 1 kg of sea ice and 2° intervals*)

T °C	C_b cal/g°C	C_i cal/g°C	ΔH_s cal/g	ΔH_i cal/g	δI g/kg	β_w g/kg	I g/kg	$\delta I \Delta H_i$ cal	$\Delta S \Delta H_s$ cal	IC_i cal	$\beta_w C_b$ cal	ΔH cal	ΔH_f cal
						1·0 per cent							
0	0·932	0·5056		−79·26	733·9	633·0	366·7	58,171	0	369	1177	59,100	59,100
−2	0·928	0·5020	−20·0	−78·25	124·8	203·7	796·3	9,763	0·4	797	372	11,420	70,520
−4	0·891	0·4984		−77·22	41·1	120·7	879·3	3,177	0·3	873	210	4,410	74,930
−6	0·856	0·4946		−76·19	21·1	89·5	910·4	1,611	0·3	897	152	2,660	77,590
−8	0·839	0·4910	−47·1	−75·13	11·4	72·7	926·7	859	54·6	906	123	1,940	79,530
−10	0·827	0·4871		−74·06	7·3	62·4	936·1	540	27·0	909	105	1,580	81,110
−12	0·815	0·4835		−72·99	5·1	55·8	942·3	374	12·1	908	92	1,390	82,500
−14	0·806	0·4798		−71·89	3·9	51·1	946·8	283	7·7	905	83	1,280	83,780
−16	0·797	0·4760		−70·79	3·3	47·3	950·4	231	5·4	901	76	1,220	84,990
−18	0·790	0·4722		−69·68	2·9	44·1	953·5	203	4·7	897	68	1,180	86,170
−20	0·782	0·4684		−68·55	2·5	41·3	956·2	173	4·6	892	65	1,140	87,300
−22	0·774	0·4646	−38·6	−67·42	7·5	34·4	961·3	508	143·6	891	54	1,600	88,900
−24	0·769	0·4610		−66·26	6·4	23·7	968·2	425	144·7	889	37	1,500	90,400
−26	0·768	0·4573		−65·09	2·9	16·3	972·9	189	67·5	886	25	1,170	91,780
−28	0·767	0·4535		−63·90	1·5	12·7	975·1	96	35·4	881	20	1,040	92,620
−30	0·765	0·4498		−62·70	0·86	10·8	976·3	54	20·1	878	17	980	93,590
−32	0·761	0·4461		−61·49	0·63	9·6	977·0	99	14·2	868	15	940	94,540
−34	0·757	0·4423		−60·26	0·45	8·8	977·5	27	9·3	861	13	920	95,460
−36	0·749	0·4385		−59·03	0·37	8·2	977·9	22	7·7	854	12	900	96,360
−38	0·748	0·4348	−44	−57·76	0·33	7·6	978·3	19	8·1	847	12	890	97,250
−40	0·748	0·4312		−56·5	0·27	7·2	978·6	15	6·8	840	11	880	98,130
−42	0·747	0·4275		−55·3	0·51	6·1	979·0	28	73·8	833	9	950	99,080
−44	0·746	0·4237	−48	−53·6	0·54	4·3	979·5	29	71·2	827	6	940	100,030
−46	0·745	0·4200		−52·6	0·32	2·7	979·9	17	36·0	819	4	890	100,920
−48	0·743	0·4163		−51·3	0·19	1·9	980·2	10	19·2	812	3	860	101,770
−50	0·740	0·4125		−50·1	0·10	1·4	980·3	5	12·0	805	2	840	102,610
−52	0·736	0·4090		−48·9	0·07	1·1	980·4	3	7·1	798	2	820	103,430
−54	0·728	0·4051		−47·7									

D

(salts + brine + ice), and in the process melting δI grams of ice, dissolving δS grams of salts, requiring ΔH_i and ΔH_s calories per gram respectively. The specific heats of the components are C_i, C_s and C_b. All of these quantities are temperature
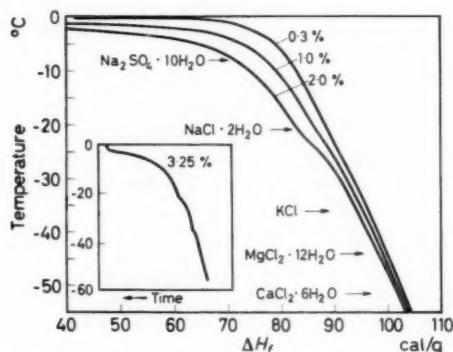

Figure 9. Heat of melting versus temperature and salinity. Inset shows melting curve which should be proportional to heat of melting curves (After NELSON and THOMPSON[3])
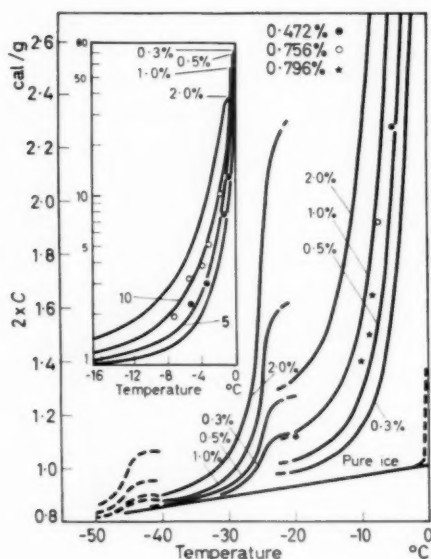

Figure 10. Specific heat of sea ice illustrating erratic behaviour due to crystallization of salts (After MALMGREN[1])

dependent and dependent also on the composition and concentration of the solution. We will call ΔH over an interval of $1°C$ the ' specific heat ' of sea ice, recognizing that the value obtained depends on the placement of the temperature interval and includes a latent heat effect. The total heat required to melt the sea ice completely and bring it to $0°C$ we will call the ' heat of melting.' It is impossible to separate the latent and specific heat effects; a true latent heat has no meaning because of the absence of a unique melting temperature. The heat of melting is the sum of the specific heats from the given temperature to $0°C$.

The theoretical specific heat curve is shown in *Figure 10* and indicates some of the difficulties that may be encountered in the experimental determination of this property. The ordinate on the figure is the heat required to change 1000 grams of sea ice by $2°C$. The heat of melting,

$$\Delta H_f = \Sigma \Delta H$$

is plotted in *Figure 9*. If the derived phase relations are correct the melting curve (inset) should have the same shape as the heat of melting curve and this is clearly the case. The amount of heat involved in the crystallization of the salts can be large over certain temperature ranges, although it is always less than the heat of fusion of ice over the same interval.

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ACOUSTICS AND THE NEW ARCHITECTURE

E. G. RICHARDSON *

Physics Department, King's College, University of Durham, Newcastle upon Tyne

After giving an outline of the brief history of the scientific study of acoustics, various techniques for improving old buildings and ensuring that new buildings and open-air auditoria have good acoustics are described, and the need for the designer to bear the artistic aspect in mind is pointed out.

IN EUROPE since the end of the Second World War a unique opportunity has presented itself to architects in the requirement for new auditoria or replacement of old ones. Whereas if the catastrophic destruction had occurred a century ago, most architects could have built new churches and concert halls untrammelled—if that is the *mot juste* —by consideration of what the congregation or audience might or might not hear, their education in the professional schools of today obliges them to make this consideration of prime importance. All this change of outlook has occurred within the lifetime of the writer who can remember in his youth the miles of wire strung as palliatives of bad acoustics between the walls of certain halls; however if these were dislodged or fell into disuse the acoustics were affected not one jot.

The modern scientific treatment of acoustical problems began with the late Professor SABINE[1] of Harvard who with his portable organ and stop watches, made many measurements of reverberation and absorption in New England buildings at the beginning of this century. His methods, translated into electronic techniques, are still used, though this translation has not been entirely an advantage. Sabine rightly regarded the ear as the final arbiter, a fact which some acoustical engineers have tended to forget until recently.

The practice of architectural acoustics is both a science and an art, which means that when the scientist has got matters to his satisfaction, he must still take a concensus of opinion among those who are going to listen to it. We shall revert to the artistic aspect later in this article.

Sound Absorption and Reflection

Over the past fifty years, besides improving recording techniques, the manufacturer and the scientist in their respective laboratories have been busy devising new sound-absorbing materials and testing

them. Since the reverberation time and its variation with frequency is an important criterion for acoustical assessment, we must know how the absorption coefficient of a specimen varies over the audible pitch range (*Figure 1*).

The principal use of such materials, applied to surfaces in auditoria, is to produce a desired reverberation time. It is now established what reverberation time a room of a certain volume should have for clear listening to speech or music— a little larger in the latter case—and also how it should vary with frequency. A gentle rise with frequency is favoured. The absorption in question is the sum of all that afforded by the walls plus that of the persons and objects in the room. The resonant absorbers shown in *Figure 1(d)* can be inserted in the ceiling to correct irregularities in the frequency-response curve.

Although it is generally agreed that the position of the absorbing surfaces does not materially affect the time of reverberation, the directivity of the sound pattern and its concentration in certain spots is noticeably affected by the positions at which large absorbing or reflecting surfaces are placed. In general, one can state that reflectors should be near the source of sound, absorbers further off—on the ' live end, dead end ' principle. Thus one often finds today, large reflectors placed over the dais in a form which gives rein to the architect's taste (*Figure 2*). The shell in which a dance band often sits is also designed to throw the sound well down the hall.

In arranging his reflecting surfaces, the architect must not forget the listening requirements of the choir or orchestra, the members of which feel lost if they cannot hear the other performers. (The writer, as a member of a cathedral choir, experienced the discomfort of singing in other churches where it was not possible to hear the other parts owing to the absence of suitable reflecting surfaces in the chancel. An overloaded organ accompaniment is no solace on such occasions!)

One important scientific advance which has been made since the War is the appreciation of the relative importance of what a listener hears directly from the source and what comes to him after reflection from other directions. This is illustrated by the work of JUNIUS[2] who used directional microphones in the newly built Liederhalle in Stuttgart.

The requirements for speech in a hall are perhaps less stringent than those for music. All the audience want is to understand what the speaker means! This condition can be met in a large lecture hall or out-of-doors by the use of a public address system to amplify the speech and relay it to the more distant members. Listening for them will be improved if a delay can be introduced in the reproduction corresponding to the time the speaker's voice takes to reach the same point by the intervention of a tape-recorder and several pick-up heads.

Studies by Use of Models

Several people have thought of studying the acoustical properties of a projected auditorium by models, the smaller geometrical scale being compensated by higher frequencies to give shorter wavelengths. CANAC[3] uses ultrasonic sources and pick-ups in this respect. The conditions to be met are stated by MUNCEY[4] thus:

' The conditions to be fulfilled by such a model are that both it and the full scale enclosure should have the same boundary shape but with dimensions in the desired ratio (m), and that they should be lined over corresponding areas with materials having equal impedance ratios at frequencies mf and f'.

NICKSON and MUNCEY[5] showed by experiments with a quarter-scale model of a rectangular room that over a frequency range of one octave and for the commonly accepted acoustical tests of room performance such as reverberation time, form of reverberation decay, transmission characteristic, frequency irregularity and pulse pictures, the behaviour of the model and the original corresponded to within the limits of accuracy of the impedance matching of their boundary surfaces.

CONNOR[6] however, who has studied the use of models for this purpose, doubts whether they are worth the trouble of construction.

Adaptability of Buildings

Difficulties arise when a building has to be used on occasion for music or speech, because the musician likes it rather resonant. This is a problem of the hall with a high vault and is perhaps more likely to be encountered in an old building. Recently the author
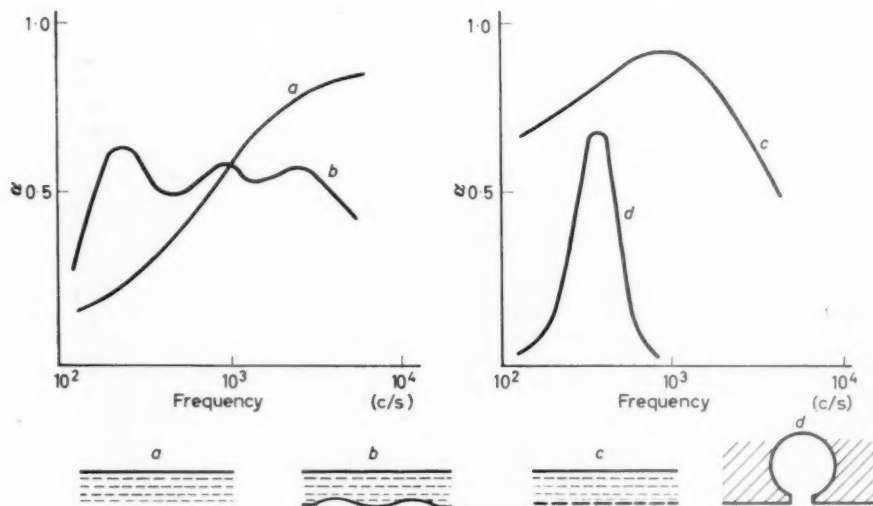

Figure 1. Four types of absorbent layer with their characteristics: (a) porous with rigid coating; (b) with flexible coating; (c) with perforated coating; (d) Helmoltz resonator (Professor C. W. KOSTEN, Technical Aspects of Sound. Courtesy Elsevier)
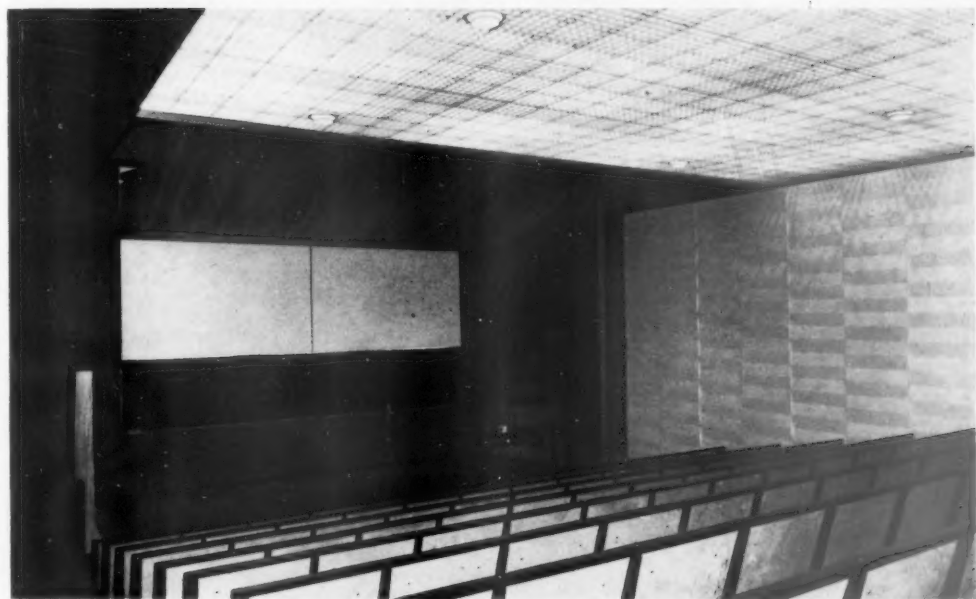
Figure 2. *Acoustical treatment of lecture hall (note the reflectors above and around the dais)*
(Courtesy H. D. PARBROOK *and* G. R. BEECH, *A.R.I.B.A.)*

Figure 3. *' Pamphonic' line source loudspeakers in St Albans Cathedral (Photo: Kate Venables, St Albans)*

was asked to do something to one such hall to make it tolerable for speech days. In earlier years one would have had to instal large and ugly trumpet loud-speakers directed down over the heads of the audience, but nowadays the arrays of loud-speakers in column can be set up as in *Figure 3*. These are portable and have the property of a line source to radiate a beam in a direction at right angles to their length (*Figure 4*). Because this property, as with light waves, is a question of the size of the sources in relation to the wavelength, and therefore to the frequency, they are usually installed in pairs for high and low pitch, one each side of the hall. By their use, little energy travels up to the vault to cause embarrassing echoes. They are a boon in Norman and Gothic cathedrals.

Not only the reverberation time but the manner in which the reflected echoes die away is important. Sometimes in a large hall with hard surfaces, pronounced repercussion of sound energy may strike a listener after the direct sound has passed. Such a condition is often distracting but it can be avoided if the ceiling is kept low and efforts made to diffuse the sound uniformly. Then the average loudness after the primary source is cut off falls steadily to zero.

Artistic Factor

It has been remarked at the outset that the adjustment of the acoustics of an auditorium is not merely a matter of scientific manipulation, like setting-up a galvanometer to record currents. Even when the scientist has done his best, there will still be found some listeners—especially among musicians—who find listening unsatisfactory in that particular hall. Such critics often subconsciously confuse other things with their acoustic impressions; what they have been accustomed to in the past, whether the seats are comfortable, even the quality of the coffee served in the interval. Musicians are very conservative. An outcry arose in certain quarters when the Royal Festival Hall in London was opened, because it did not sound like the old Queen's Hall and the organ was not designed on familiar lines. Later when they had become accustomed to its new acoustics the majority liked it. This may be due to a number of factors but one is undoubtedly the precision of musical definition gained by the audience hearing a good proportion of sound directly without reflection.

The scientist is not helped by the vagueness of the terminology used by musical listeners in describing the acoustics of a hall. Perhaps he gains his best reward when to his question about the acoustics of a hall to a listener after a concert he gets the answer, ' I was not aware of it '.

Open Air Auditoria

Although in Britain our climate does not lend itself to much building of open-air auditoria, they are of course common a little nearer to the Equator and they raise problems of their own. CANAC[7] has made
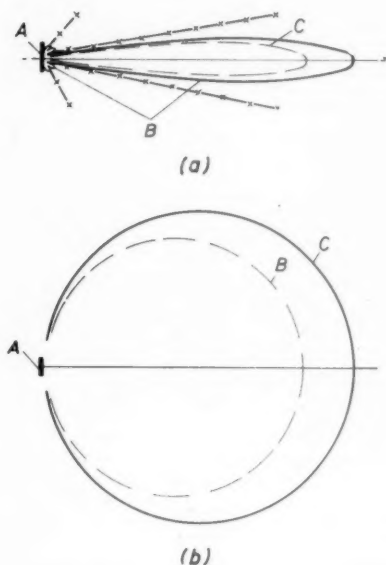

Figure 4. Line source loudspeakers: general form of contours of constant loudness, (a) vertical plane, (b) horizontal plane

a careful study of those which remain in Southern Europe from classical times and has shown that the Ancients, whether through empirical or more scientific methods, knew well how to design an open-air theatre for good acoustics.

Modern developments are to be found in the Hollywood Bowl and the more recent one at Sydney of which NICKSON and MUNCEY[8] made acoustical studies in advance of construction.

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DETERMINATION OF HYDROGEN IN METALS: A CARRIER GAS METHOD

F. R. COE

Chief Chemist, British Welding Research Association, Abington, Cambridgeshire

A new method is described for the rapid determination of hydrogen in metals. By using an inert carrier gas technique together with a thermal conductivity detector, complicated glass vacuum systems are avoided and small amounts of hydrogen in the carrier gas may be measured directly. The simplicity of the system makes it eminently suitable for routine control purposes and its flexibility is a useful feature in research.

HYDROGEN, derived from furnace gases at high temperatures, is readily absorbed by metals in the molten state and, although partly rejected during cooling, persists as a trace impurity after solidification. The amounts of hydrogen involved range from 0·1 to 1 ml/100 g for aluminium, 1 to 10 ml/100 g for steel, up to 10 to 500 ml/100 g for titanium. Some idea of the problem confronting the analyst is obtained when we remember that 1 ml/100 g is equivalent to 0·00009 per cent by weight.

Even in such small concentrations hydrogen has important effects on the properties of metals. Thus it can promote porosity and cracking in castings, brittle fracture and delayed fracture under stress in fabricated components, blistering in sheet material and underbead cracking during the welding of hardenable steels. The lack of any satisfactory explanation of the precise role of hydrogen in these mechanical deteriorations together with the increasing demands of product quality control have emphasized the need for sensitive and rapid methods of measurement both in research and industry.

The Determination of Hydrogen

Unlike other elements, hydrogen in metals is loosely bound and its determination in steel is normally accomplished by vacuum extraction of the solid sample at 600–700°C followed by analysis of the evolved gases in a low-pressure system. Such techniques require expensive and fragile glassware, operators skilled in the maintenance of the systems and in general are time-consuming to operate. In an effort to avoid these disadvantages, SHANAHAN and COOKE[1] in 1958 developed a carrier gas technique in which hydrogen evolved by the sample at 650°C was swept away by an inert gas at atmospheric pressure oxidized to water by a heated catalyst and determined by titration with Karl Fischer reagent. Using nitrogen as the carrier gas and a 50 g sample they were able to show that the carrier gas procedure had an accuracy comparable to that of vacuum extraction methods. In the B.W.R.A. laboratories attempts

to apply the Shanahan and Cooke method directly to 5 g samples yielding total volumes of hydrogen as small as 0·005 ml (N.T.P.) failed, owing partly to the high blank rates encountered and partly to uncertainties in determining the endpoint of the Karl Fischer titration at these low levels.

Principle of the B.W.R.A. Method

The principle of the thermal conductivity cell or katharometer has been described by DAYNES[2] and this type of detector has been widely used in gas chromatography. The sensitivity of the detector depends among other things on the difference in the thermal conductivities of the gases to be analysed. In the case of steel 90–95 per cent of the gas evolved at 650°C is hydrogen, which possesses a high thermal conductivity. Argon on the other hand shows the lowest thermal conductivity of commercially available inert gases. Consequently, extremely small concentrations of hydrogen in an argon stream will produce responses in the katharometer bridge circuit. When applied to the determination of hydrogen in steel very simple equipment can be used (*Figure 1*). A stream of argon flows over the surface of the sample in a furnace at 650°C and sweeps away evolved hydrogen, the katharometer being used to analyse the carrier gas as it leaves the furnace. A second furnace for the oxidation of the hydrogen and the Karl Fischer titration are thereby eliminated. The response of the katharometer may be followed with a galvanometer or, if a permanent record of the test is required, a pen recorder may be used. The apparatus is shown diagrammatically in *Figure 2*. Cylinder argon is supplied to the system via a fine-control needle valve and a mercury U-tube flowmeter calibrated to deliver 0–20 ml of argon per minute. A length of flexible tubing then carries the gas to a pivoted board, on which is mounted a sample loading lock (described below) a small furnace operating at 650°C, and the katharometer cell-block. From the cell the argon passes *via* a short length of tubing to waste.

Figure 1. Apparatus for the determination of hydrogen

A constant current of 350 mA is supplied to the cell from a 6V battery and the output from the bridge circuit taken to a single point recorder.

To calibrate the system, it is necessary to inject small volumes of hydrogen into the argon stream before entering the furnace and to correlate these with peak areas measured from the recorder trace. For this purpose a small burette is used and is shown in detail in the inset in *Figure 2*. Cylinder hydrogen *via* the open limb of T_1, is used to fill the space above the mercury and up to T_2 which is a small *Neoprene* pad closing over the open end of a 1-mm bore stainless steel tube. Small volumes of hydrogen allowed to escape *via* T_2 into the argon stream are measured on the 0–2·0 ml pipette (*B*) and corrected to N.T.P. In this way very small volumes of hydrogen can be injected, the estimated error of measurement being of the order of ± 0·002 ml at N.T.P. Volumes from 0·005 to 0·5 ml (N.T.P.) are injected in this way to cover the range of hydrogen contents (0·1–10 ml/100 g) encountered with steels. Typical traces obtained for 0·035, 0·121, and 0·319 ml of injected hydrogen are shown in *Figure 3* which also illustrates the zero stability of the system. Peak areas are measured either with a planimeter or by direct integration of the recorder output. The latter method is more rapid and at B.W.R.A. has been achieved by means of a ball and disc mechanism

similar to that described by LINGANE[3]. Using this device peak areas are evaluated automatically as they appear and presented as numbers on a revolution counter. A typical calibration curve of hydrogen volume *vs* peak area is shown in *Figure 4*. A precision resistance (0–2 Ω variable) is used in parallel with the katharometer bridge output and this provides various sensitivity settings for the recorder. This is especially useful when a series of samples of widely varying hydrogen contents are being examined. For normal working the sensitivity is such that a peak area of 1 cm^2 represents 0·02 ml H_2 (*i.e.* 0·4 ml per 100 g for a 5 g sample). With the highest sensitivity 1 cm^2 represents 0·001 ml H_2 (*i.e.* 0·02 ml per 100 g for 5 g sample).

Variations in carrier gas flow-rate do not affect the zero stability of the detector but sensitivity falls with increasing flow-rate since the instantaneous hydrogen-in-argon concentration becomes smaller. Hence it is important to maintain the flow-rate constant within fairly close limits and a high quality needle valve is used. The other variable which requires careful control is the current supply to the katharometer since the output from the bridge circuit is proportional to the cube of this current. In practice a well maintained 6V car battery provides a stable supply and no errors have been detected from this source.
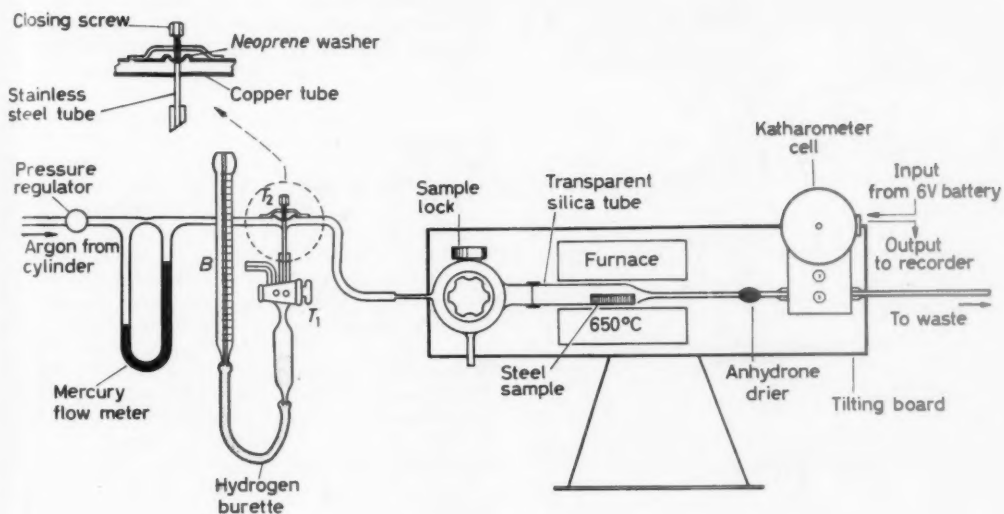
Figure 2. Diagram of apparatus

Treatment of Samples

Traces of air accidentally admitted to the system produce peaks very similar to those due to hydrogen. The problem of introducing actual steel samples without admitting air is overcome by using a special loading lock, designed and constructed in these laboratories and illustrated in *Figure 5*. In consists of a cylindrical brass block free to rotate on O-rings inside a closely fitting hollow brass cylinder. The centre block is drilled to accommodate the sample and a stoppered inlet port, gas inlet port and connection to the furnace are provided on the outer cylinder. The sample is loaded in Position (a), the stopper replaced and the argon flow sweeps any entrained air away to waste. The centre block containing the sample is rotated through 90° and the sample is free to slide into the furnace, Position (b). The whole operation occupies about twenty seconds, no air wave appears on the recorder, nor is the zero affected. For unloading, the operations are repeated in reverse and when not in use the lock is kept in Position b).

The problem of sampling, storage and preparation of specimens prior to the determination of hydrogen is a considerable one involving many factors and cannot be discussed here, but an excellent review of present practice has been given recently by EBORALL[4]. In the B.W.R.A. laboratories specimens are stored in solid CO_2 after sampling and before analysis the sample is washed in acetone, then ether, and finally connected to a rotary pump for about 5 seconds to remove the last traces of wash liquid and frost. The sample is then rapidly transferred to the loading lock. Hydrogen contents determined by a conventional vacuum extraction method and by the proposed carrier gas method are compared in *Table 1*.

Table 1. Hydrogen contents, ml per 100 g

Steel	Vacuum extraction method	B.W.R.A. carrier gas method
A	4·4	4·69
B	4·1 (av. of 6 tests)	4·17 (av. of 3 tests)
C	4·4	4·38
D	3·8	3·52
E	5·2	5·22
F	3·8	4·00
G	4·4	4·23
H	4·4	3·90
I	3·8	3·25
J	3·1	3·12
K	3·4, 3·4	3·42, 3·48
L	3·3	3·60

Evolution of hydrogen from these small samples is usually complete after fifteen minutes at 650°C and the form of the curve closely resembles that due to injected volumes of pure hydrogen.
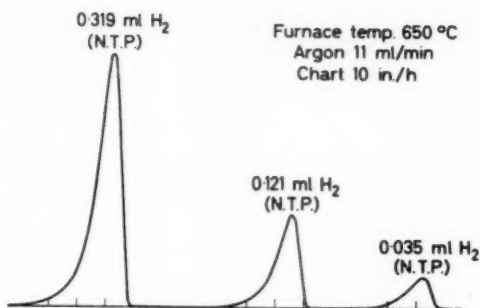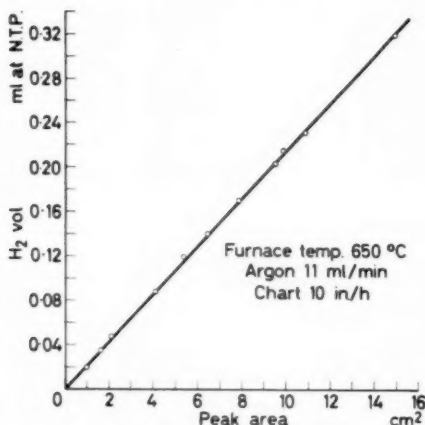
Figure 3. *Typical recorder traces*

Figure 4. *Calibration curve*

The katharometer is zeroed with the carrier gas flowing and trace impurities in the argon have no effect provided that their amounts remain constant and no reaction occurs in the furnace. Traces of water coming into contact with a steel at 650°C, however may break down to form an oxide film, the resulting hydrogen passing on to be measured by the katharometer. During early work this effect was noticed and traced to the high permeability to moisture of rubber and plastic tube connections. The incorporation of an *Anhydrone* drying bulb on the gas inlet tube of the loading lock removes the last traces of moisture and the procedure then becomes free from the blank problems which are associated with other methods.

Conclusions

The removal of hydrogen from steel involves a diffusion process which can be described by Fick's Law, so that the time required for complete evolution is governed ultimately by the geometry of the sample. Because of the high sensitivity of the katharometer small samples can be used—for example 1 in. × $\frac{1}{4}$ in. diameter cylinders weighing about 5 g. This presents an immediate advantage in that one determination is completed in about fifteen minutes and the apparatus is immediately available for the next test. The procedure thus becomes eminently suitable for routine control under plant conditions. By avoiding elaborate vacuum systems the initial capital outlay is extremely modest and maintenance and running costs are negligible.

For research purposes the carrier gas procedure has been found more flexible than the conventional vacuum methods. During investigations into the relationship between hydrogen and mechanical
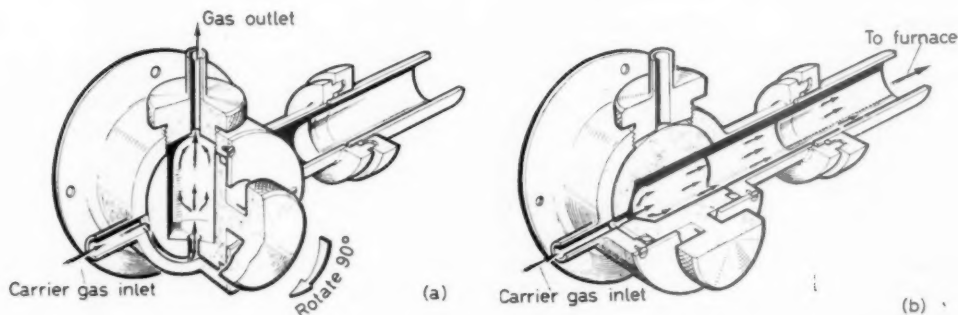

Figure 5. *Sample loading lock*

properties where large numbers of samples are involved, behaviour trends can be rapidly evaluated. In welding in particular it has become possible to measure the hydrogen associated with a weld-pool immediately the arc is extinguished and the information obtained in this way will eventually lead to a better understanding of the part played by gases in determining weld characteristics.

Carrier gas techniques are already well established and may eventually supersede classical vacuum procedures in many applications because of their simplicity and low cost.

The use of thermal conductivity cells for the detection of other gases besides hydrogen may be expected as a future development and the simultaneous determination of several gases in mixture, such as may be obtained from a melted specimen, may become possible when the experiences of the organic chemist with gas chromatography have been fully exploited in the metallurgical field.

The design of this apparatus is the subject of British Patent Application No. 14051/60. The illustrations were included in a paper and discussion given at a Symposium on 'The Determination of Gases in Metals', London, May 1960 and are published by courtesy of the Iron and Steel Institute

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3 LINGANE, J. J. and JONES, S. L. *Anal. Chem.* (1950) **22**, 1220
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SURVEY

National Gas Turbine Establishment

Most of the work done at the N.G.T.E. is of the type to be expected of an establishment devoted to the development of gas turbines and ramjet engines. Anyone who has seen and heard the Boeing 707 take off will know that it is not exactly the mascot of the Noise Abatement Society, nor has it read Sir Hugh Beaver's air pollution report. N.G.T.E. devotes considerable effort to the study of both problems, and it might not be inappropriate to mention in the hearing of the 707 the work on recirculation to increase lift.
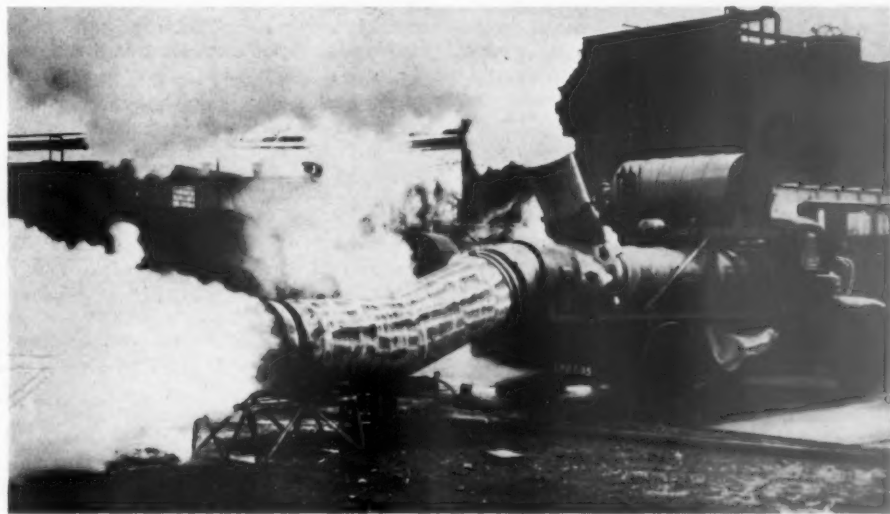

Figure 1. Turbojet firefighter (courtesy National Gas Turbine Establishment. Crown copyright reserved)

Figure 2. The experimental foundry of the B.S.C.R.A.

A novel use of the turbojet is as a fire-extinguisher (*Figure 1*) making use of its property of passing enormous quantities of air for its size and weight. The exhaust has to be modified—the oxygen content reduced by burning more fuel, and the temperature lowered by injection of water. The apparatus consists of a Viper turbojet with reheat (after-burning) followed by water injection, mounted on a 5-ton lorry chassis. The apparatus is designed to connect to the water mains, the water pressure is increased to 100 lb/in.[2] by four turbo-centrifugal pumps and delivered to injection tubes. The machine ejects exhaust at the rate of 50,000 ft³/min at 120°C containing 37 per cent water vapour.

The Fire Research Station is now doing experimental work with this apparatus.

British Steel Casting Research Association

The B.S.C.R.A., which has been in existence since 1953, is unique in that it is the only collective research organization in the world devoted exclusively to to steel castings. Membership includes several foundries in the Commonwealth as well as in the United Kingdom, and in addition to dealing with individual technical enquiries, a considerable amount of general research is in hand directed to improving the standard of both the sand compacts and the castings; they are also concerned with such matters as atmospheric pollution, noise and ventilation.

It has been found that if a thermally stable, refractory layer of zirconia, silica, alumina or magnesia lies between the molten steel and the sand casting then even under conditions of high ferrostatic pressures metal penetration into the sand can be eliminated. Paints used for this purpose consist of the refractory, a bonding agent, *e.g.* dextrin and linseed oil, and a suspending agent, generally sodium bentonite. However, this mixture cracks badly under certain conditions—if heated rapidly or if sand mixtures of low dry strength are used—and it appears that the cause of this cracking is the sodium bentonite and sodium alginate is a successful substitute.

Some steelmaking processes are apparently often rather haphazard at present. To remove carbon oxygen is injected until the operator considers that the steel *looks* right. However, the B.S.C.R.A. has published control charts specifying the amount of oxygen required to produce a given carbon reduction at different bath temperatures. Phosphorus is

removed in the same operation but the amounts are so small that the oxygen required for this is negligible.

B.S.C.R.A. is also recommending a more accurate control of temperature in furnaces as at present there is a good deal of heat wastage. They specify optimum temperatures for specific alloys, and will test individual furnaces thermostatically so that an accurate check can be kept on the process.

Man Powered Flight

The Question to the House on Man-Powered Flight by the Member for Brighton Pavilion (Mr Teeling) brings to the imagination the most enchanting picture of a Chino-Regency aeronaut flying in a graceful and leisurely fashion around the domes and pinnacles of the Pavilion. Apparently, however, what is required to propel the modern man-powered flying machine is two or more champion cyclists with well-developed muscles; at least this is so in the case of the *flycycle* which is being developed at Queen's University by Mr Nonweiler, senior lecturer in aeronautical engineering. This machine, a two-seater, with an $8\frac{1}{2}$ ft propeller mounted in the tail, should be capable of achieving speeds up to 30 m.p.h. Other aircraft are being developed elsewhere on the wing-flapping technique, for example the Hartman ornithopter (*Figure 3*), and Mr Donald Perkins, senior scientific officer at the Royal Aeronautical Establishment at Cardington, is developing a machine based on the principle of a fixed inflatable wing craft with a special form of transmission coupling the propeller to bicycle pedals.

Mr Teeling drew the attention of the House to a prize of £5000 being offered by a Mr Kremer for a Man Powered Flight machine; technically the aircraft would be considered as gliders and no permit to fly or certificate of airworthiness would be required, although competitors are advised to be well insured.

The conditions are as follows: the entrant, designer and pilot must be citizens of the United Kingdom or the British Commonwealth and the aircraft must be designed and flown in the British Commonwealth; the machine must be heavier than air and the use of lighter-than-air gases is prohibited. It must be powered and controlled by the crew over the entire flight, and no devices for storing energy for take-off or for use in flight are permitted. No part of the machine must be jettisoned during any part of the flight, including take-off, and the crew should be those persons in the machine during take-off and flight, and there should be no limit set to their number. No member of the crew is permitted to leave the aircraft at any time during take-off or flight. Furthermore, one handler or ground crew may assist in stabilizing the machine at the wing-tip during take-off. All attempts, which must include the take-off run, must be made over approximately level ground and on a course to be approved by the Royal Aero Club. All attempts shall be in still air, which is defined as a wind not exceeding a mean speed of approximately 10 knots, over the period of the flight. The Royal Aero Club is to act as observer and make final judgments.

Microinstruments Series

Dr BOYD's article on *Instruments for Space Research* (p. 290) is the last in the above series. A complete set of reprints of the seven articles in this series can be obtained from Butterworths, 4/5 Bell Yard, London, W.C.2. for 10/6d.

Figure 3. The Hartman manpowered ornithopter (designed by Mr D. CAMPBELL). Power, rowing action by arms to flap wings; span, 36 ft; mean chord, 4ft; weight, 282 lb. Constructed as conventional glider. (Reproduced by courtesy of Associated Newspapers and of 'Flight')

BOOK REVIEWS

Treatise on Analytical Chemistry
(A comprehensive account in three parts)
Part I. Theory and Practice. Volume I
I. M. KOLTHOFF and P. J. ELVING (*Eds*)

(*xxvi + 809 pp; 9½ in. by 6½ in.*)

New York and London: Interscience Publishers Inc.
$17.50, 133*s* (single) or $15.00, 115*s* (subscription)

THIS treatise is intended to provide a ' concise, critical, comprehensive and systematic treatment of all aspects ' of analytical chemistry. This is obviously a monumental task, and even the detailed plan of the whole work is not yet available. The present volume, which does no more than cover a small part of the range promised for Part I, is divided into two sections. The first, consisting of four chapters, is on 'Analytical Chemistry, its Objectives, Functions, and Limitations ', and the second, to be completed in Volume 2, on 'Application of Chemical Principles ', and seventeen distinguished authors have contributed the total of nineteen chapters.

It is a valuable book, and most of it could be required reading for all chemists interested in the chemistry of solutions, not only for those whose field is analytical chemistry. Most of the chapters give excellent accounts of the theoretical principles relevant to the chosen topic, and, in addition, constantly emphasize the use of these principles in practical cases. A study of these chapters cannot fail to stimulate the reader, and to provide a fuller insight into the physical chemistry which underlies many of the new advances in analytical chemistry. An exceptionally wide field is covered and, though some of the information provided is readily available elsewhere, it is useful to have it included within one cover together with accounts of other, less familiar, matters. The chapters on chemical equilibria, acid–base theory and on solubility, among others, undoubtedly attain the aims of concision and comprehensiveness desired by the editors.

Having said this, it is not presumptuous to offer some criticisms. Here and there throughout the book, and, in one instance, for most of a chapter, the encyclopaedic ambitions of the authors lead to a series of trite statements which cry out for editorial excision. For example, there is a section on Physical Methods in a chapter dealing with reaction kinetics which consists of the following gem: ' Physical methods which have been used for gathering data include spectrophotometry, potentiometry, dilatometry . . . amperometry, viscometry, among others.' The proportion of book space wasted by this sort of thing, though small, is still too large. Cross-indexing between chapters is mainly well-done, though apparently irreconcilable statements about the effect of particle size on solubility of barium sulphate are made in two successive chapters (pp. 694, 737). There are some brief expositions of college level physical chemistry which are too short to be really valuable to those who need them, and are rapidly skipped by those who do not. It might have been wiser in these instances to allow for the availability of adequate texts on these topics. Minor blemishes of this kind do not however detract seriously

from the usefulness of the book and, if the whole series maintains the standards set by this volume, it should prove to be a work of enduring value.   H.J.V.T.

Principles of the Extraction of Metals
D. J. G. IVES

(*57 pp; 8½ in. by 5½ in.*)

London: The Royal Institute of Chemistry. 6*s*

THIS monograph is the third in a series sponsored by the Royal Institute of Chemistry for the guidance of teachers of chemistry at G.C.E. Advanced Level or above. The aim is to enable the topic to be taught in such a way that there shall be no subsequent ' unlearning ' before more advanced treatment.

The introductory survey of thermodynamic ideas and relationships is adequate for what follows, and very necessary for those who only have infrequent dealings in this field. Some pyrometallurgical processes are then discussed, making use of Ellingham's graphical method of plotting standard free energy against temperature. This is an excellent section where a great deal of information has been collected for oxides, sulphides and chlorides. The examples chosen very clearly illustrate the value of these plots, particularly the carbon–oxygen relationships which are most enlightening.

There follows a short chapter on ore types and their deposition geologically, together with the choice of extraction methods in very general terms. In the last chapter there is a description of some typical metallurgical processes, an indication of the plant required to handle them, and a full and descriptive account of the extraction and purification of copper in illustration of all that precedes it. Finally there is a cursory review of some hydro-metallurgical processes. Throughout the approach is through thermodynamic studies, although the limitations are recognized and the importance of kinetic studies duly emphasized.

This brief treatise dealing with a subject of such complexity cannot be wholly satisfying but it has much to offer and should prove stimulating to those who teach metal extractions. It is difficult, however, to see how much can be related to teaching in schools where, with very few exceptions, thermodynamic studies are not attempted and heats of reaction must remain the basis of chemical affinities.   T.A.G.S.

Structure and Properties of Thin Films
C. A. NEUGEBAUER, J. B. NEWKIRK and D. A. VERMILYEA
(*Eds*)

(*xiv + 561 pp; 11¼ in. by 9 in.*)

New York, London: John Wiley and Sons Inc.   120*s*

IN September 1959 a three-day conference in New York was sponsored by the American Air Force and the General Electric Company. This book consists of the reviews and papers read at that conference and the ensuing discussions between scientists of international repute.

It is divided into six sections each concerned with a particular aspect of the study of thin films. These are the formation, mechanical, electrical and magnetic properties of thin films, the molecular chemistry of interfaces and the theory of surfaces. Every section is opened by a review paper each of which sets an excellent standard for the following original papers. In fact the majority of the material is restricted to the properties of evaporated metal films which means that the book is titled with excessive generality. However, the growth of this field of physics has been extremely rapid and the publication of a book is amply justified because the techniques and understanding which have evolved must be of interest to many workers in solid-state physics generally.

Two particular fields in which rapid progress is being made are the studies, firstly of the formation of thin films, which is yielding valuable information about the behaviour of imperfections in solids, and secondly of ferromagnetic thin films which, through their nearly two-dimensional character, look promising in the possibility of their providing a theoretically tractable approach to ferromagnetism generally. These advances are easily seen in the appropriate sections of this book.

One conclusion which emerges clearly from the discussion between experts in the different disciplines represented here is that too many observers have been uncertain about the structural condition of their films and that structure is most important in determining many of their properties. It is to be hoped that this stituation will soon be righted.

A criticism which applies to all the papers is that their value to the non-specialist or even the worker in another section of thin-film physics would have been considerably increased by the inclusion of abstracts so as to provide some means of assessing their content without a thorough study.

The presentation is attractive with some particularly beautiful photographs at the beginning of each section. The comparatively quick publishing is excellent as the value of this class of information lies partly in its being distributed rapidly. It is a book which is indispensable to all workers in thin film physics and of direct interest to anyone concerned with the physics of the solid state.

M.P.

Handbook of Automation, Computation and Control
Vol. 2. Computers and Data Processing

E. M. GRABBE, S. RAMO and D. E. WOOLDRIDGE (*Eds*)

(*xxiii + 1070 pp; 9¼ in. by 6 in.*)

New York: John Wiley; London: Chapman & Hall. 140s

THE purpose of this series of three substantial volumes written by a panel of specialists is to provide for technologists and managers a summary of present knowledge on automation and control. Volume I has already been reviewed in this journal (Feb. 1959) and dealt with 'Control Fundamentals'; the third volume is titled 'Systems and Components'.

Volume 2 is concerned with the design and use of computers, of both digital and analogue type. Following a short glossary of computer terminology, there are five main sections of very varying length. Three of these deal with digital computers, their programming, use and design; the remaining two describe analogue computers and unusual systems.

Section B on programming (written by J. W. CARR III) is a book in itself being over a quarter of the entire volume. Detailed descriptions are given of methods of programming for a number of well-known American computers. The Russian *STRELA* is also described but the reader will look in vain for references to British machines. Perhaps the part of this section of most interest to the specialist is that dealing with ' automatic programming ' or methods of making computers simpler to use. Among much material not readily available elsewhere. the information about computer activities in the Soviet Union is particularly welcome. After reading accounts in this chapter of so many diverse methods, the reader may feel that programming is becoming more complicated rather than simpler. Fortunately, attempts are now being made to co-ordinate much of this work and international computer languages such as *ALGOL* and *COBOL* are being formulated.

Section C begins with a description of facilities available on computers, followed by two slim chapters of value to a potential buyer of a computer. The first deals with physical requirements (space, refrigeration, power) and staffing (programmers, operators, engineers) whilst the second summarizes the steps involved in installing a computer to replace an existing system. Some of the early machines were installed after insufficient preparation; a number of pitfalls are listed here. This section concludes with chapters on applications of computers. Inevitably much condensation has been necessary but one feels that this has been overdone in the chapter on scientific applications. A very short chapter is concluded by an equally short list of references and none to work published later than 1956.

Section D deals with the building of computers, particularly the well-established American ones. For example, there are chapters on logical design, transistors, magnetic cores, arithmetic elements, *etc*. The design and application of analogue computers is treated quite fully in Section E. Both these sections give detailed descriptions of techniques employed with computers two or three years ago.

This work will be a useful addition to the library of any computing organization; it contains much of interest to the manager, programmer and designer although the restriction to the American scene does impose a limitation. The specialist may find little that is new in his own field; he will however discover some interesting neighbouring fields. The work may have the greatest appeal to the student in the technical college. The book is well produced and detected errors have been few. The original of table 2 on page 2-36 has half of the values incorrectly rounded; these errors have been duly transmitted.

This series is a very ambitious venture: more ruthless editing and the elimination of material duplicated in some of the chapters would have produced a better balance. T.V.

Chemical Engineering Practice
Vol. II: Works Design Etc.

H. W. CREMER and S. B. WATKINS

($vi+390+xvii$ pp; 10 in. by 6 in.)

London: Butterworths. 95s

THIS volume is from the series on Chemical Engineering Practice being produced under the general editorship of CREMER and WATKINS. The title is a little clumsy but perhaps necessarily so since collected together here are a number of quite different subjects all of which are on the fringe of chemical engineering practice. The section headings are Works Administration, Factories Acts and other Legislation, Works Safety and Patents as well as Works Design, Layout and Execution. Each of these sections is separately dealt with by acknowledged experts.

None of these subjects being truly chemical engineering, the aim would appear to have been to give to chemical engineers enough background to make them aware of present procedures, and to help them to communicate with the specialists they meet in the course of their work. Such a purpose would certainly be achieved by this volume although naturally no subject is treated as thoroughly as chemical engineering subjects are treated in the other volumes in this series. This is particularly true of the section on Works Design where however the broad principles of site selection, civil construction, plant installation and contractual procedures are excellently discussed.

The section on Factory Legislation is a particularly valuable and readable account of this legislation from the point of view of the chemical engineer. With the chapter on Patents it will provide a continuously useful reference to chemical engineers as they meet these special subjects. Works Administration is a more controversial subject. It was particularly disappointing for instance to notice the small mention given to research which nowadays in any technologically progressive organisation is a very important management technique.

As a whole, however, it might well be claimed that this volume forms a valuable guide to the chemical engineer who is, or intends to become a director of a chemical firm.   P.A.F.W.

Moisture in Textiles

J. W. S. HEARLE and R. H. PETERS

($ix + 203$ pp; 8¼ in. by 5½ in.)

London: Butterworths and The Textile Institute

THIS book puts together lectures on moisture in textiles that were given at Manchester College of Technology by seven well-known contributors to the subject. It is an excellent book which suffers little from multiple authorship.

The subject is dealt with in relation to the water in the atmosphere and as such covers many important technical phenomena, particularly the effect of heat of sorption on conditioning, drying, and the buffer effect of textiles on

temperature change. There are also chapters on the theory of adsorption in fibres, the diffusion of heat and moisture through masses of fibres, and diffusion in fibre-forming substances. Other chapters deal with the effect of moisture on electrical, optical and mechanical properties. There is no noticeable overlap between the chapters by different contributors, yet very little has been missed from the extensive literature that is available on the relationship of moisture in the atmosphere to that in textile fibres, even such practical details as the value of a large mass of porous absorbing material in a constant relative humidity room being mentioned. It is the first book, so far as the reviewer is aware, that covers this important field of science and it will appeal both to those concerned with moisture in factories and to the research student.

There is an unfortunate mistake in *Figure 47* which has been transferred from the original paper: there should be no hole in the plate indicated by ' B C '. Production and printing are excellent.   A.B.D.C.

Business Films, how to Make and Use them

PETER SPOONER

($ix + 360$ pp $+ 14$ ads; 8¼ in. by 5½ in.)

London: Business Publications Ltd.   45s

Business Films is an unusual book with an unusual title. The author is not content to theorize on possible ways in which the use of the ciné camera might benefit the industrial manufacturer but illustrates these by reference to some twenty-eight actual cases spread over a wide variety of purposes. The imaginative executive should have little difficulty in seeing just where a film might help him to solve his own problems.

Costing, an all important feature when a new venture has to be brought before the board, has been made as simple as possible, for the author never fails to quote the price of each piece of apparatus mentioned, or to give some idea of the cost of any particular operation. In short *Business Films* should certainly give the non-technical administrator a good idea of what would be involved in any project embracing the making and use of films and serve as an insurance against his being ' blinded by science ' or falling a victim of ' Parkinson's Law '.

On the technical side the book does not profess to be a text-book or a highly technical treatise on the principles of cinematography, nevertheless it should certainly enable any competent photographer—amateur or professional—to attempt a motion-picture study with every hope that a professional-looking job will result. The language is clear and the style vivid, while the text is illustrated by simple—perhaps in some cases almost too simple—line diagrams. A ten-page directory of firms dealing with film equipment and services, and a competent index round off a most useful volume dealing with the application of the ciné film to industrial purposes.   E.T.B.F.